

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXXV.

FEBRUARY 12, 1915.

No. 4

ANNUAL GENERAL MEETING.

Col. E. H. HILLS, C.M.G., D.Sc., F.R.S., PRESIDENT, in the Chair.

The Report of the Auditors of the Treasurer's accounts for the year 1914 was read, and is given on p. 226.

The Annual Report of the Council was partly read.

The Address was delivered by the President, after which the Gold Medal was handed to Professor Alfred Fowler, to whom it had been awarded for his spectroscopical investigations of Sun-spots, Stars, and Comets, and for his successful interpretation of the phenomena by means of experiments in the laboratory (see pp. 355 to 362).

The following proposal of the Council, of which due notice had been given to the Fellows, was put to the Meeting and carried:—

“That this Meeting approves of the admission of women as Fellows and Associates of the Society, and requests the Council to take all necessary steps to render their election possible.”

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 363.

The meeting adjourned at 6.30 p.m.

After the adjournment the President announced that the Council had met, and that a Petition to the King for a Supplemental Charter to enable women to be elected as Fellows and

Associates had been duly sealed, and would be forwarded to the Home Office.

The thanks of the Meeting were given to the retiring President, Vice-Presidents, and other Members of Council, and also to the Auditors of the Treasurer's accounts and to the Scrutineers of the ballot.

Harold William Acton, Royal Observatory, and 55 Devonshire Road, Greenwich, S.E. ; and
Herbert William Unthank, B.A., King's College, Cambridge,
were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Thomas Hugh Close, Chief Draftsman, Existing Lines Department, Sydney, Romney, Fern Street, Pymble, Sydney, Australia (proposed by Hugh Wright) ;

Charles Monro Hector, M.D., B.Sc., Lower Hutt, Wellington, New Zealand (proposed by C. E. Adams) ;

Robert Meldrum Stewart, Superintendent, Time-Service, The Observatory, Ottawa, Canada (proposed by Otto Klotz) ;

S. D. Tscherny, Professor in the University and Director of the Observatory, Warsaw, Russia (proposed by O. Backlund) ; and

C. T. Westland, Christchurch, New Zealand (proposed by J. W. Nicholson).

REPORT OF THE COUNCIL TO THE NINETY-FIFTH ANNUAL
GENERAL MEETING OF THE SOCIETY.

The following table shows the progress and present state of the Society:—

	Patron	Honorary Members	Fellows		Associates	Total
			Compounders	Annual Subscribers		
1913 December 31	I	I	243	477	48	770
Since elected	...	+1	+2	+34	+3	...
Deceased	...	...	-7	-7	-3	...
Resigned	...	...	...	-6	...	...
Since compounded	...	...	+2	-2	...	...
Removed from list	...	...	...	-8	...	...
1914 December 31	I	2	240	488	48	779

Mr. Knobel's Account as Treasurer of the Royal

RECEIVED.

Balances, 1913 December 31 :—	£	s.	d.	£	s.	d.
At Bankers', as per Pass-book	232	4	4			
Cheque not credited till 1914	2	2	0			
At Bankers' on Deposit	60	0	0			
In hand of Assistant Secretary on Account of Turnor and Horrox Fund	1	12	6			
In hand of Assistant Secretary on Petty Cash Account	4	19	8			
					300	18 6
Dividends :—						
£1,250 Metropolitan 3-per-cent. Stock ...	35	4	0			
£2,000 Swansea Corporation 3½-per-cent. Stock	65	12	6			
£3,500 East Indian Railway 3-per-cent. De- benture Stock	98	10	10			
£3,500 London and North-Western Railway 3-per-cent. Debenture Stock	98	15	4			
£4,000 Midland Railway 2½-per-cent. Deben- ture Stock	93	19	2			
£1,000 Lancashire and Yorkshire Railway 3-per-cent. Preference Stock	28	4	4			
£2,400 Gas Light and Coke Co. 3-per-cent. Debenture Stock	67	13	0			
£2,000 Commercial Gas Co. 3-per-cent. Deben- ture Stock	55	8	9			
					543	7 11
Received on account of Subscriptions :—						
Arrears	133	7	0			
Annual Contributions for 1914	718	4	0			
" " in advance	10	10	0			
Admission Fees	77	14	0			
First Contributions	65	2	0			
					1,004	17 0
Composition Fees					103	19 0
Sales of Publications :—						
At Society's Rooms	25	2	0			
At W. Wesley & Son's	120	16	1			
Less discount, 10 per cent.	12	1	6			
					108	14 7
Half share of proceeds of sale of Herschel's Collected Papers, received from the Royal Society	11	10	1			
					145	6 8
Subscriptions for 23 sets of Franklin-Adams Charts					241	10 0
Sales of Photographs					34	2 6
Income Tax refunded by Commissioners of Inland Revenue					33	16 2
Interest on Money on Deposit at Bankers' ...					8	9 8
					<u>£2,416</u>	<u>7 5</u>

Examined and found correct.

(Signed) G. J. NEWBIGIN.
H. P. HOLLIS.
J. R. LEESON.

Astronomical Society, from January 1 to December 31, 1914.

PAID.				£	s.	d.	£	s.	d.
Assistant Secretary: Salary	...	...	...	250	0	0			
" " Editing Society's Publications	...	...	...	50	0	0			
Clerk: Salary	...	...	...	100	0	0			
							400	0	0
House Duty	...	...	...	2	12	6			
Fire and Servants' Insurance	...	...	...	10	5	3			
							12	17	9
Printing, etc. :—									
Monthly Notices	...	...	...	497	19	7			
Memoirs	...	...	...	41	1	2			
List of Fellows and Miscellaneous	...	...	...	38	10	6			
Photo-engraving and Lithography	...	...	...	38	5	10			
Sir W. Herschel's Collected Works: half share of cost of binding	...	...	...	4	7	6			
							620	4	7
Grant to Lunar Nomenclature Committee	...	...	...				21	0	0
Balance of Expenses for Production of the Franklin- Adams Charts	...	...	...	159	4	0			
Honorarium to Mr. Melotte	...	...	...	25	0	0			
							184	4	0
Cataloguing Astronomical Literature for the Inter- national Catalogue	...	...	...				30	0	0
Reproduction of Photographs for sale	...	...	...				17	8	2
Turnor and Horrox Fund: purchase of Books for Library	...	...	...	22	14	10			
Purchase of Vols. of <i>Astronomische Nachrichten</i>	...	...	...	20	0	0			
Binding for Library	...	...	...	31	1	10			
							73	16	8
Expenses of Meetings	...	...	...	17	12	0			
Lantern Attendance	...	...	...	4	0	0			
Time-Signal: Rental of Wire	...	...	...	5	0	0			
							26	12	0
Subsn. to <i>Centralstelle für astronomische Telegramme</i>	...	...	...	1	7	1			
Telephone Subscription	...	...	...	6	10	0			
Registration of Telegraphic Address	...	...	...	1	1	0			
Postage and Telegrams	...	...	...	104	12	5			
Carriage of Parcels	...	...	...	9	0	3			
Stationery and Office expenses	...	...	...	15	11	2			
							138	1	11
House expenses: Allowance and sundry expenses	...	...	...	59	16	4			
Coal, Gas, and Electric Light	...	...	...	61	13	5			
Decorating Rooms	...	...	...	32	17	0			
Sundry fittings and repairs	...	...	...	8	10	3			
Sundries	...	...	...	4	14	0			
							167	11	0
Lee and Janson Fund: Grants to Mrs. McDowell	...	...	...	15	0	0			
" " " " Mrs. Henkel	...	...	...	5	0	0			
							20	0	0
Subscription to Napier Tercentenary	...	...	...				2	0	0
Cheque-book and Bankers' Charges on Cheques	...	...	...				0	12	2
Balances, 1914 December 31 :—									
At Bankers', as per Pass-book	...	...	...	195	19	2			
Cheque not credited till 1915	...	...	...	2	2	0			
At Bankers', on Deposit	...	...	...	500	0	0			
In hand of Assistant Secretary on Account of Turnor and Horrox Fund	...	...	...	3	17	8			
In hand of Assist. Sec. on Petty Cash Account	...	...	...	0	0	4			
							701	19	2
							£2,416	7	5

Report of the Auditors.

We have examined the Treasurer's accounts of receipts and expenditure for the year 1914, and certified the same to be correct. The cash in hand on December 31, 1914, including the balances at the Bank, etc., amounted to £701, 19s. 2d., including the sum of £500 on deposit.

The funded property of the Society is the same as at the end of the year 1913.

The books, instruments, and other effects in the possession of the Society have been examined. They appear to be in a satisfactory condition, with the exception of a few instruments of ancient date.

A list has been laid on the table of the names of those Fellows who are in arrear for sums due at the last Annual General Meeting of the Society, together with the amount due against each Fellow's name.

(Signed) G. J. NEWBEGIN.
H. P. HOLLIS.
J. R. LEESON.

1915 January 14.

Gifts to the General Funds of the Society.

In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2,000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2,000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

Trust Funds.

The Lee and Janson Fund: In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334 10s. 9d. East Indian Railway 3-per-cent. Debenture Stock.

	£	s.	d.		£	s.	d.
1914 Jan. 1. Balance of				1914. Grants to Mrs.			
Fund	58	18	7	McDowell	15	0	0
Dividends, East Indian				Grants to Mrs. Henkel	5	0	0
Railway	10	0	9	1914 Dec. 31. Balance of			
				Fund	48	19	4
	£68	19	4		£68	19	4

The Turnor Fund and the Horrox Memorial Fund: In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464 18s. East Indian Railway 3-per-cent. Debenture Stock. In 1876 the Society received a sum of £38 15s., the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrox: to this the Society added the sum of £55 15s., and the whole now stands in £103 6s. East Indian Railway 3-per-cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the Library.

	£	s.	d.		£	s.	d.
1914 Jan. 1. Balance of				1914. Purchase of Books	25	0	0
Fund	8	14	4	1914 Dec. 31. Balance of			
1914. Dividends, East				Fund	0	15	4
Indian Railway ...	17	1	0				
	£25	15	4		£25	15	4

The Hannah Jackson (née Gwilt) Fund: In 1861 Mrs. Hannah Jackson (née Gwilt) gave £300 Consols, which now stands in £309 18s. 6d. East Indian Railway 3-per-cent. Debenture Stock; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1914 Jan. 1. Balance of				1914 Dec. 31. Balance of			
Fund	16	10	5	Fund	25	16	5
Dividends, East Indian							
Railway	9	6	0				
	£25	16	5		£25	16	5

Assets and Present Property of the Society, 1915 January 1.

Balances, 1914 December 31 :—	£	s.	d.	£	s.	d.
At Bankers', as per Pass-book	195	19	2			
" on deposit	500	0	0			
Cheque not credited till 1915	2	2	0			
In hand of Assistant Secretary on account of Turnor and Horrox Fund	3	17	8			
In hand of Assistant Secretary on Petty Cash Account	0	0	4			
				701	19	2
Due on account of Subscriptions :—	£	s.	d.			
20 Contributions of 3 years' standing	126	0	0			
41 " 2 " "	172	4	0			
67 " 1 " "	140	14	0			
Other sums	13	1	0			
				451	19	0
Less Contributions paid in advance	10	10	0			
				441	9	0
Due from Wm. Wesley & Son for sales of Publica- tions during last quarter of 1914				15	1	9
£1,250 Metropolitan 3-per-cent. Stock.						
£2,000 Swansea Corporation 3½-per-cent. Stock.						
£3,500 East Indian Railway 3-per-cent. Debenture Stock (in- cluding the Turnor Fund, the Horrox Memorial Fund, the Lee and Janson Fund, and the Hannah Jackson (<i>née</i> Gwilt) Fund).						
£3,500 London and North-Western Railway 3-per-cent. Deben- ture Stock.						
£4,000 Midland Railway 2½-per-cent. Debenture Stock.						
£1,000 Lancashire and Yorkshire Railway 3-per-cent. Consoli- dated Preference Stock.						
£2,400 Gas Light and Coke Co. 3-per-cent. Debenture Stock.						
£2,000 Commercial Gas Co. 3-per-cent. Debenture Stock.						
Astronomical and other Manuscripts, Books, Prints, Photo- graphs, and Instruments.						
Furniture, etc.						
Stock of Publications and Photographs.						
Two Gold Medals.						

Celestial Photographs.

The following have been added to the list of Celestial Photographs reproduced by the Society for sale to the Fellows:—

R.A.S.

Ref.

No.

235. Three Minor Planet Trails. Max Wolf.
236. Nebula H iv 74 Cephei. Max Wolf.
237. Spectrum of Nebula M. 81. Max Wolf.
238. Spectrum of Dumb-bell Nebula. Max Wolf.
239. Solar Surface and Spectroheliogram, K_2 - 3 . H. Deslandres.
240. Spectroheliogram, K_3 and H_α . H. Deslandres.
241. Spectroheliogram, K_3 and H_α . H. Deslandres.
242. Spectroheliogram, H_α . H. Deslandres.
243. Spectroheliogram, Radial Velocities. H. Deslandres.
244. Spectroheliogram, Radial Velocities. H. Deslandres.
245. Saturn, 1911 Nov. 19. E. E. Barnard.
246. Spectroheliogram, K_1 and K_3 . H. Deslandres.
247. Spectroheliogram, K_3 , K_2 , K_1 . H. Deslandres.
248. Spectroheliogram, H_α Flocculi. G. E. Hale.
249. Spectroheliogram, H_α Flocculi. G. E. Hale.
250. Sun-spot Vortices, 1908 Oct. 7. G. E. Hale.
251. Solar Prominences, 1910 March 25. Yerkes Observatory.
252. Solar Prominences, 1910 Oct. 10. Yerkes Observatory.
253. Nebulous Region in Cepheus. Yerkes Observatory.
254. North America Nebula in Cygnus. Yerkes Observatory.
255. Nebulæ in Cygnus (N.G.C. 6960, 6992). Yerkes Observatory.
256. Delavan's Comet, 1914 Sept. 20. Royal Observatory, Greenwich.
257. Delavan's Comet, 1914 Sept. 26. Royal Observatory, Greenwich.

Lantern slides, 1s. each. Prints, mounted, 1s. 6d. each; unmounted, 1s. each. Postage extra.

The Award of the Gold Medal.

The Council have awarded the Society's Gold Medal to Professor Alfred Fowler, for his spectroscopical investigations of Sun-spots, Stars, and Comets, and for his successful interpretation of the phenomena by means of experiments in the laboratory. The President will lay before the Society the grounds upon which the award has been founded.

Publications of the Society.

During the past year vol. lxxiv. of the *Monthly Notices* has been published.

The following part of the *Memoirs* has also been published:—

Vol. lx. part iv. S. Chapman and P. J. Melotte: The number of Stars of each photographic magnitude down to 17^{m.0}, in different Galactic Latitudes.

OBITUARY.

The Council regret that they have to record the loss by death of the following Fellows and Associates during the past year:—

Fellows:—Alexander John Samuel Adams.

Septimus Buss.

William Garnett.*

Sir David Gill.

Sir Edwin Durning-Lawrence.

Sir George Francis Hardy.

Jasper Nicholls Harrison.

Col. George Henderson.†

Edward Vincent Heward.

Edward H. V. Melvill.

Samuel Saywell.

William Arthur Smith.

Sir John Benjamin Stone.

Thomas Thorp.

Associates:—Nils Christoffer Dunér.

George William Hill.

Edward Singleton Holden.

Obituaries are also given of Prof. S. C. Chandler and Sir Robert S. Ball, who died in 1913.

ALEXANDER JOHN SAMUEL ADAMS was born at Chelsea on 1846 January 3, and was educated at the High School, Plymouth. Entering the service of the Electric Telegraph Company at the age of fourteen, he served successively at Cheltenham, Bristol, and Reading, and, as cable relay clerk, at Haverfordwest. In 1868 he joined the Indo-European Telegraph Company, and served for three years in Persia at Tabriz and Teheran. Upon his return to England in 1871, he was appointed to the engineer-in-chief's staff at the Central Telegraph Office, ultimately reaching the position of Assistant-Controller. During this period he resided at Tottenham (1871-79), and New Cross (1879-1914). He retired in 1908.

While at Haverfordwest, Mr. Adams' attention was drawn to the influence of earth-currents upon telegraphic transmission, and from that period he made a close study, both at home and abroad, of earth-currents and magnetic storms and their connection with Sun-spots.

He died of cerebral hæmorrhage at New Cross on 1914 December 25, leaving a widow, three sons, and four daughters.

He was elected a Fellow of the Society on 1905 January 13.

ROBERT STAWELL BALL was born in Dublin on July 1, 1840. He was the eldest of the three sons of Dr. Robert Ball, a well-known naturalist. The three brothers all became distinguished in science—the eldest as Lowndean Professor of Astronomy at

* Deceased in 1913, but death not reported till 1915.

† Deceased 1906 Nov. 17, but death not reported till 1914.

Cambridge; the second, Dr. Valentine Ball, as Director of the Science and Art Museum at Dublin; and the youngest, Sir Charles Ball, as an eminent surgeon.

Robert Stawell Ball received his earliest education at a preparatory school at Dublin, proceeding in 1851 to Dr. Brindley's school at Tarvin near Chester, where he first began that study of mathematics to which he devoted so much of his later career. In 1857 he entered Trinity College, Dublin, and soon showed his aptitude for mathematics. In 1860 he obtained a scholarship at the Lloyd Exhibition. In 1861 he was Gold Medallist in Mathematics, first Gold Medallist in Experimental and Natural Science, and University Student.

It is stated that while at school Ball's interest in astronomy was awakened by reading Mitchell's *Orbs of Heaven*, which had just been published. At this time there existed hardly any books which presented astronomy in a popular form, and Mitchell's books were widely read. This may have had some influence on Ball's mind in after years, in trying to awaken others to the interest of astronomy by his many popular books and lectures. At college Ball studied the class-book on the *Elements of Plane Astronomy* which Brinkley had prepared for Dublin University. He also studied the *Principia* and Laplace. Thus prepared, he attracted the attention of Dr Johnstone Stoney, who, in 1865, recommended him to Lord Rosse as assistant astronomer, and tutor to his sons. He worked with the 6-foot reflector at Parsonstown, chiefly in observations and micrometric measurements of faint nebulae. It is pointed out by Dr. Dreyer that "Ball was the first observer with that telescope to correct the position-angles for the error due to the instrument not being equatorially mounted, but supported at its lower end by a universal joint, the fixed axis of which was horizontal, in the east and west direction. This procedure, which materially improved the observations, was a natural outcome of Ball's geometrical instincts." In 1867 Ball quitted Lord Rosse's observatory on his appointment to the professorship of Applied Mathematics in the newly founded Royal College of Science in Dublin. It was while in this position that he first began to give popular lectures on science.

In 1874 Brünnow, on account of failing health and eyesight, resigned his position as Andrews Professor of Astronomy and Royal Astronomer for Ireland, and Ball was appointed in his place. The Dunsink Observatory had been reorganised by Brünnow, who had mounted the 11 $\frac{3}{4}$ -inch object glass presented by Sir James South, to form an excellent equatorial for the researches on stellar parallax to which he devoted himself. His predecessor, Brinkley, had undertaken the same line of research. Ball determined to continue the difficult investigations thus initiated, and it was at Dunsink that he produced his more important contributions to astronomy. Some delay occurred in effecting improvements to the equatorial, and it was not till 1876 that Ball commenced his work on stellar parallax. He selected the star 61 Cygni, on which he

made a long series of observations of the difference in declination between the *preceding* component of 61 Cygni and a following small star of the ninth or tenth magnitude—only after the observations were begun he found that Brünnow, whose investigation of the same star he had intended to follow, had observed the *following* component of 61 Cygni, as had been done by Struve (with, however, a different comparison star). He decided to continue, and in 1877 he finally determined the parallax to be $+0''.4654 \pm 0''.0497$. In 1878 he began a new investigation of the difference in declination between the *following* component of 61 Cygni and the same small star as had been used by Brünnow, so that this series would form a continuation to that of his predecessor. The final result for the parallax was $+0''.4676 \pm 0''.0321$. Struve had obtained, from the mean of two methods, a parallax of $0''.505$, and Bessel, as rediscussed by C. A. F. Peters, $0''.360$. Ball remarks that the accordance between his two series is so close that it is clearly due to some extent to the chapter of accidents, and he adds, "It would, however, seem that these investigations render it probable that the annual parallax of 61 Cygni is nearer the half second found by Struve than the third of a second found by Bessel."

In 1876 Ball commenced a systematic search for stars with a large annual parallax, which occupied him for the succeeding five years. In selecting the stars for investigation, he adopted the views which had been expressed by Schiaparelli in one direction, and by Johnstone Stoney in another. Schiaparelli had remarked that it is possible the stars which are really nearest to us belong, in some sort, to the same system as our Sun, are therefore animated by somewhat the same motion in space, and consequently do not exhibit the phenomenon of proper motion to a remarkable degree. In a communication to the Royal Society Johnstone Stoney says: "The minute crimson stars which are met with here and there in the sky seem to be either very small stars, or stars enormously distended by heat. It is very desirable that the proper motion and parallax of these bodies should be inquired into, on the chance that some of them may be found to owe their colour to being very small and therefore very close to us." Accordingly, Ball selected for his inquiry stars with small proper motion, and others which were red stars. His observations are contained in two memoirs published in Parts III. and V. of the Dunsink Observations. The first series gives the investigation of 42 stars, and the second of 367 stars: every observation was made by Ball himself. The practical conclusion he thus announces: "In the great majority of cases the results pronounce emphatically against the supposition of a parallax large enough to be detected amid the errors of observation inseparable from the method adopted. In no case do they afford reliable indications of a parallax large enough to be detected by the method of reconnoitring." Besides 61 Cygni, Ball made determinations of the parallax of Groombridge 1618, $\pi = +0''.322 \pm 0''.023$, and of 6 Cygni, $\pi = +0''.482 \pm 0''.054$.

He also essayed a determination of the parallax of Piazzini III. 242, but the result was negative.

Sir Robert Ball's fame in the history of science will rest more upon his eminent power as a mathematician than upon his contributions to astronomy.

The origin of his great work, *The Theory of Screws*, may be best given in his own words. He says: "In the spring of 1869 I happened to attend a lecture at the Royal Dublin Society, given by my friend Dr. G. Johnstone Stoney. For one illustration he used a conical pendulum: he exhibited and explained the progression of the apse in the ellipse described by a heavy ball suspended from a long wire. I was much interested by his exposition, and began immediately to work at the mathematical theory of the subject, in the endeavour to understand it more fully. I was thus led to investigate some general problems relating to the small oscillations of a particle on a surface. Certain results, at which I arrived, seemed to me interesting and novel. They appeared as a paper in the *Quarterly Journal of Pure and Applied Mathematics*, 1869, under the title 'A Problem in Mechanics.' This paper was soon followed by another on 'The Small Oscillations of a Rigid Body about a Fixed Point under the Action of any Forces, and more particularly when Gravity is the only Force acting' (*Transactions of the Royal Irish Academy*, vol. xxiv.). The subject then began to develop into what I ventured to call *The Theory of Screws*. The first memoir with this title appeared in 1872; the twelfth and last in 1897." Ball, however, published three additional memoirs: "Further Developments of the Geometrical Theory of Screws" (1901); "On the Reflection of Screw Systems and Allied Questions" (1902); and "Some Extensions of the Theory of Screws" (1903, 4).

Only brief reference can be made to this important work in the present notice, and the following account is taken from the fuller description of the *Theory of Screws* in the *Proceedings of the Royal Society*, vol. cxi. (Obituaries, p. xx):—

"Ball's *Theory of Screws* gives a very complete geometrical treatment of the problems of small movements in rigid dynamics, and in that respect is unique among English books. The small first edition appeared in 1876, and the large and comprehensive volume was published by the Cambridge University Press in 1900.

"The keynote to the whole method consists in the use of the 'screw,' consisting of a line in space together with an associated length or 'pitch.' This geometrical entity has a double use, representing either the most general system of forces, or the most general kind of small displacement. In the former case it gives the axis and pitch of a 'wrench,' in the latter of a 'twist.' For either physical interpretation, the geometrical development is the same. Interesting derivative relationships between screws can be followed out. For example, *reciprocal* screws, when a wrench along one does no work for a twist along the other; and *conjugate* screws, when a wrench along one produces instantaneous

twist along the other. Notable use is made throughout the work of the 'cylindroid' surface, which appears in statics as the surface traced out by the resultant of two wrenches of varying intensities along given screws. Ball was not the actual discoverer of the cylindroid (Hamilton and Plucker had found its chief property earlier), but he certainly counts as its chief patron. He took always a lively interest in any development of its properties, and a beautifully made model placed in the collection of Cambridge University serves as a memento of its former owner."

"For a most admirable and appreciative survey of the scope of Ball's work on screws, reference may be made to a review by Henrici (*Nature*, 1890) of the treatise *Theoretische Mechanik Starrer Systeme* by Gravelius, which is founded mainly upon Ball's memoirs. An excellent account was given by Ball himself in his presidential address to the Mathematical Section of the British Association in 1887. He there uses some geometrical abstractions, quaintly personified, as speakers in a discussion; and, under this whimsical garb, reveals the essence of his methods very pertinently and clearly. Through all Ball's work there shows a fine enthusiasm for his subject and a most generous appreciation of the discoveries of others. In the year 1879 the Royal Irish Academy awarded him the Cunningham Gold Medal, and his name thus occurs in a list which includes also those of Casey, MacCullagh, Hamilton, Jellett, and Salmon. By his many and excellent contributions to the geometry of kinematics and dynamics, Robert Stawell Ball assuredly takes an honourable place on the roll of Irish mathematicians."

Among Ball's contributions to the *Monthly Notices* may be mentioned: "On a Simple Approximate Method of Calculating the Effect of Refraction upon the Distance and Position-Angle of two Adjacent Stars"; "On a Transformation of Lagrange's Equations of Motion in Generalised Co-ordinates"; "On the Single Equation which comprises the Theory of the Fundamental Instruments of the Observatory"; "Micrometric Observations of Nova Andromedæ"; and "On the Orbit of the Binary Star ζ Ursæ Majoris."

By his numerous books and lectures Sir Robert Ball is conspicuously identified as the most popular expositor of astronomy this country has ever possessed. His popular books *The Story of the Heavens*, *Starland*, *In the High Heavens*, *Time and Tide*, *The Cause of an Ice Age*, *The Story of the Sun*, *Great Astronomers*, and others are all written in a clear and attractive style and have been widely read. In 1880 he published an excellent text-book on the *Elements of Astronomy*, and in 1908 he issued a very useful *Treatise on Spherical Astronomy*, for the use of Cambridge University Students.

For more than thirty years Sir Robert Ball has been renowned for the popular lectures he delivered throughout this country, and in so many places in Canada and the United States. An important research advances astronomy in a specific direction, but it is a question whether the science generally may not be advanced

ultimately in a greater degree, by the presentation of astronomical facts and astronomical researches in lucid and attractive lectures to large numbers of people, who would be thus encouraged and stimulated and guided to more advanced study. In an admirable discourse on lecturing, delivered by Mr. Goschen over thirty years ago, he said: "The lecture has a great advantage over reading in its educational influence, inasmuch as it gives a power to the lecturer of exciting interest and enthusiasm for his subject by his inspiring personality. The voice and manner of the lecturer will do more than any tricks of style can do. A book may excite interest and enthusiasm, but personal contact is much more likely to do it. Writing that inspires is rarer than inspiring speech, and lecturers have not fulfilled their function unless they inspire the interest and enthusiasm of their hearers. Lecturers, if they are suggestive, are not only sign-posts pointing towards the direction in which you ought to go, but they see you safely started on your journey, and take you to wider fields of literature and wider fields of thought." It was these attributes of a lecturer which Ball possessed in an eminent degree. The great popularity which he attained is convincing evidence of the wide interest in astronomy which he thus excited. It is common knowledge how small the influence may be which affects a receptive mind, and leads it to further study and development, and in this way Ball's lectures cannot but have given a strong impulse in this country to the advancement of the study of astronomy.

On the death of Professor J. C. Adams at the beginning of 1892, Sir Robert Ball was elected to succeed him as Lowndean Professor of Astronomy and Geometry, and also as Director of the University Observatory at Cambridge; positions which he held up to the time of his death. Soon after, he was elected a Fellow of King's College, Cambridge. He was an honorary M.A. of Cambridge, and an LL.D. of Dublin. It is recorded that as a lecturer on the mathematical side of astronomy, Ball showed the same lucid qualities which made him so effective in a more popular sphere. He gave the young student an insight into the methods of the classical writers in celestial mechanics and prepared the way for the study of the later advances.

In 1884 Ball became Scientific Adviser to the Commission of Irish Lights, in succession to Tyndall, and he always took the greatest delight in the annual cruise of the Commissioners round Ireland to inspect the lighthouses. On January 25, 1886, he received the honour of knighthood from the Lord Lieutenant of Ireland. He was elected a Fellow of the Royal Society in 1873 and served on the Council in 1897-98. He was President of the Royal Astronomical Society 1897-99, and for ten years was a member of the Council.

Sir Robert Ball had a charming personality. His kindly and sympathetic nature, his full appreciation of the labours of others, and his keen sense of humour, made him greatly beloved and respected by all his friends. For the last two years of his life

he was seriously ill, but happily without suffering, and he died at Cambridge on November 25, 1913, and was buried in St Giles churchyard, where also lie the remains of his illustrious predecessor. In 1868 he had married the daughter of Dr. W. E. Steele, Director of the Science and Art Museum at Dublin, who survives him with his four sons and two daughters.

He was elected a Fellow of this Society 1875, March 12.

E. B. K.

SEPTIMUS BUSS was born on 1836 January 14. He was the son of an artist, and originally intended to follow his father's profession. In his early years, while pursuing the study of art he was also preparing for matriculation at London University with a view to taking Holy Orders. During the years 1854-1859 he was an exhibiter at the Royal Academy and other institutions, and occasionally found relaxation in painting after his Ordination in 1860. After holding curacies at St. Peter's, Regent Square, and Holy Trinity, Haverstock Hill, he was appointed Chaplain to St. Pancras Workhouse in 1864 and held that position until 1873. He was then presented to the living of Wapping, and for the next seven years was occupied with arduous parochial work. In 1881 Mr. Buss was appointed to the Parish of Shoreditch, where he laboured with great zeal in social and religious work for eighteen years. He was particularly active in the causes of temperance and municipal reform. His final appointment was to the rectory of St. Anne and St. Agnes, Gresham Street, in 1899. Here there was practically no parochial work, and he applied himself to courses of mid-day lectures to city men. For several years he dealt with Church History, but from about 1911 onwards he gave courses on popular astronomy, among which a course on "Astronomy in the Bible" attracted special attention. These lectures were well illustrated and were greatly appreciated by large audiences.

For over sixty years Mr. Buss was associated with the work of the North London Collegiate School for Girls, which was founded by his elder sister; first as instructor in drawing, and for the last fifty-five years as teacher of Scripture.

In 1860 Mr. Buss married his cousin, Maria Emma Buss, and their golden wedding was celebrated in 1910; the long partnership was broken by the death of Mrs. Buss two years later. In 1913 he married Miss Kate Dyke, the youngest daughter of Mr. Richard Dyke, of Clifton.

He died on 1914 September 20.

He was elected a Fellow of the Society on 1912 January 12.

By the death of Sir DAVID GILL astronomy has lost one of its ablest and best-known leaders. By his widespread activity, his close association with all the great enterprises of observational astronomy, and by the energy and enthusiasm of his character, he had come to hold an almost unique position in astronomical counsels; and the withdrawal of his great motive power leaves a universal

sense of loss. By his individual achievements and by his leadership he has exerted an incalculable influence on the progress of all that pertains to precision of observation. It will be our task in this notice to give an outline of his work as an astronomer; but to understand his immense influence it is necessary also to realise the personal character of the man. Those who came in contact with him felt the charm of his personality. In some indefinable way he could inspire others with his enthusiasm and determination. Enjoying a life crowded with activity, surrounded by an unusually wide circle of friends, he was ever ready and eager to encourage the humblest beginner. It was no perfunctory interest that he displayed. He was quick to discern any signs of promise, and no less outspoken in his criticism; but, whether he praised or condemned, few could leave him without the truest admiration and affection for his simple-hearted character.

David Gill was born at Aberdeen on the 12th of June 1843. His family had long been associated with that city, where his father had an old-established and successful business in clocks and watches of all kinds. In due course he entered the Marischal College and University, Aberdeen. At that time J. Clerk Maxwell was a professor there, and his teaching had a great influence on the young student. Judged by ordinary standards, Maxwell was not a successful lecturer; but there were some students who could catch a part of his meaning as he "thought aloud" at the blackboard, and feel the impression of his personality in after-lecture conversation, and these found him an inspiring teacher. Gill was among these, and he became imbued with a zeal for experimental science, which soon manifested itself in his setting up a small laboratory in his father's house.

Up to the age of twenty, Gill's scientific interests appear to have had no particular inclination to astronomy; but in 1863 he became desirous of securing an accurate time-service at Aberdeen. Encouraged by a visit to Professor Piazzi Smyth at Edinburgh Observatory, he succeeded in interesting Professor David Thomson in his efforts. There was at that time an old observatory at King's College, Aberdeen. Together the two men unearthed and set up in adjustment a portable transit-instrument which had long been disused; the sidereal clock was overhauled and fitted with contact-springs for the electrical control of other clocks; and the observations for time-determination now became the chief occupation of Gill's leisure evenings.

It was not long before he began to seek for an instrument which would give him a wider scope for astronomical work. He met with a second-hand silver-on-glass mirror of 12-inches aperture and 10 feet focal length. The task of mounting this equatorially gave him the first opportunity of displaying that skill in instrumental designing for which he afterwards became so famous; and the whole mounting was made from his working-drawings. He made the driving-clock with his own hands.

Among the chief results obtained with this telescope were some

excellent photographs of the moon. At that time Lord Lindsay (son of the Earl of Crawford) was planning to erect an observatory at Dun Echt, 13 miles from Aberdeen. Having seen these photographs, he visited Gill in order to see his instruments and methods of work. The acquaintance thus formed led to Gill's receiving early in 1872 an invitation to take charge of the Dun Echt Observatory that was about to be erected.

At this time Gill was actively at work all day, his father having retired, leaving the business in his hands; it was only his evenings that could be devoted to scientific pursuits. He had married in 1870, and was living in Aberdeen near his little observatory. To accept Lord Crawford's offer meant the giving up of a flourishing business, and a heavy pecuniary sacrifice; but by now astronomy was claiming him irresistibly, and he made the choice without hesitation. The business that he now relinquished had never been congenial to him; but the time he had devoted to the clockmaker's art had not been wasted, for it is reasonable to believe that his natural mechanical genius was in no small measure fostered by this early training.

Gill's direction of the Dun Echt Observatory lasted from 1872 to 1876. It was his task to design and install the fine equipment that was rapidly acquired—for him a foretaste of the similar work he was afterwards to carry out at the Cape. But this period of his life is chiefly remembered, not for observations made at Dun Echt, but for an expedition to the island of Mauritius on the occasion of the Transit of Venus 1874. It was in preparation for the work at Mauritius that he first began to use the heliometer, an instrument with which his most celebrated researches were afterwards made. The 4-inch heliometer of the Dun Echt Observatory (afterwards purchased for the Cape) was made under Gill's superintendence by Repsold; and, whilst it was in the course of construction, he took the opportunity to visit Hamburg for the meeting of the Astronomische Gesellschaft in 1873. Besides attending this congress, Gill visited several of the Continental observatories, and in this way made the acquaintance of the leading European astronomers, and also obtained an insight into the organisation of the large observatories.

The Mauritius expedition introduced him to two of the great problems, which more especially he made his life's work—the determination of the solar parallax, and the problems of geodetic measurements. Deferring, for the present, consideration of the scientific results of this expedition and of another expedition to Ascension Island in 1877, we pass on to the next great step in his career.

Early in 1879, David Gill was appointed by the Admiralty to be Her Majesty's Astronomer at the Cape of Good Hope, in succession to Mr E. J. Stone. Before sailing for the Cape he made another tour of the European observatories, visiting Paris, Leiden, Groningen, Hamburg, Copenhagen, Helsingfors, and Poulkovo. Perhaps the most important fruit of these visits was his acquaint-

ance with Dr. Auwers and Dr. Elkin, which led to much valuable co-operation between them.

On the 29th of May 1879 he arrived at Cape Town and took up his duties at the Observatory. The only instruments which he found in use were the Airy transit-circle, a 7-inch equatorial, and a photoheliograph. The Observatory, founded in 1820, had fulfilled a useful duty by the regular work of meridian observation, the early Cape Catalogues being a most valuable source for the positions of the southern stars. Its history had also been marked by one conspicuous achievement, Henderson's detection of the parallax of α Centauri—the first proof that the parallax of a fixed star could amount to a measurable quantity. Whilst the instruments and observations might be open to many criticisms, the work was, for that period, fairly efficient. But the standard of precision was being raised, and Gill's standard was the highest of his time. To his mechanical insight the faulty design and unsatisfactory repair of the old instruments was apparent, and he would not rest until the defects were remedied. He was no believer in the Airy type of transit-circle, incapable of reversal, but it was many years before he could obtain an instrument according to his ideals. Meanwhile it was necessary to make the best of the existing telescope. The object-glass was deteriorated, the micrometer-screws were worn, and the whole instrument was in need of a thorough overhaul. He at once set to work upon it with his usual energy, and so transformed it that for differential work it left little to be desired. The Airy transit-circle performed useful service until 1901, when it was replaced by the new reversible transit-circle. It is still used at times for special researches. The 7-inch equatorial was likewise submitted to a thorough overhaul.

The only immediate addition to the equipment was the 4-inch heliometer, which was secured by Gill by private purchase. With this provision he was content to spend the first few years of his Directorship, until he should be in a stronger position to press his claims on the Treasury. The principal additions made during the subsequent years that he spent at the Cape were:—the 6-inch Dallmeyer lens used for the Photographic Durchmusterung, acquired in 1884, the 7-inch heliometer in 1887, the astrographic refractor erected in 1890, the Victoria telescope (a 24-inch photographic refractor with guiding telescope and spectroscopic equipment) in 1898, and the reversible transit-circle in 1901. He was thus for his first researches limited to instruments of very moderate size and cost, and the success with which he afterwards obtained an adequate provision for the Observatory was due both to the confidence inspired by his brilliant early work and to his pertinacity in pressing the needs of astronomy.

If, from his many and varied services to astronomy, we were asked to pick out the one in which he arrived at the most striking and complete success, there is little doubt that the answer would be his determination of the solar parallax. At the time when Gill, by accepting the charge of the Dun Echt Observatory,

definitely embarked on an astronomical career, a celestial event of the first magnitude was approaching—the Transit of Venus of 1874. Great expectations were entertained that this would afford an improved determination of the solar parallax, a fundamental constant which was at that time involved in unsatisfactory uncertainty. Preparations were made by the leading observatories and astronomical societies on an unprecedentedly lavish scale, and expeditions were despatched to different parts of the world. Lord Lindsay was co-operating in the work, and the Dun Echt expedition took up a station at Mauritius. Gill had already formed the opinion (which he afterwards conspicuously advocated) that there were other and better methods of finding the sun's parallax involving far less expense. He believed that the observations of the transit were of such a nature that the results would be inaccurate and capable of more than one interpretation, for too much depended on the arbitrary judgment of those who had to discuss the observations. He determined therefore to use the opportunity of the expedition to make trial of another method, namely, morning and evening observations of the minor planet Juno, which was then favourably situated. He considered that a single observer could by heliometer observations of a minor planet obtain results comparable in accuracy with those derived from all the Transit of Venus observations together. Unfortunately, the heliometer was delayed in arrival at Mauritius, and the first half of the opposition of Juno was lost. Observations in the latter half were secured on twelve evenings and eleven mornings, but the parallax factor was then small. The result, $8''.77 \pm 0''.041$, though disappointing owing to the causes mentioned, gave a clear indication of the value of the method, and this pioneer effort served its purpose as a preliminary to a more ambitious attempt. From that time onwards Gill had a strong conviction of the value of the heliometer for work of the highest refinement, and he acquired his remarkable skill in using it. The Transit of Venus was observed by the party; but Gill appears to have formed so low an opinion of the trustworthiness of the measures that he took little interest in their subsequent use.

In 1877 an exceptionally favourable approach of Mars to the Earth offered a good opportunity for a renewed attack on the problem of the solar parallax. Gill, who had resigned his position at Dun Echt, began to prepare for an expedition to Ascension Island for this purpose. He fully expected that Mars would, owing to its large disc, prove to be a less satisfactory subject for heliometer observation than a minor planet, which is practically indistinguishable in appearance from the comparison stars; but the parallax factor was so much more favourable than for any minor planet then known that the opportunity was not to be missed. His anticipations proved correct. The value of the solar parallax now found showed a great improvement on any previous determination. The result, $8''.78$, with a probable error of $\pm 0''.012$, marks a new stage of advance. But Gill by this

work became more than ever convinced that the definitive determination of the constant must rest on minor planets.

For his third and final attempt in 1888-9 the minor planets Iris, Victoria, and Sappho were chosen. Instead of measuring the diurnal parallax, he proceeded this time by the combination of observations made at widely separated stations. This involved a great scheme of co-operation in which many observatories and individuals took some part. The actual heliometer measures of the planets were made mainly by Gill and Finlay at the Cape, by Elkin and Hall at Yale, and by Peter at Leipzig. Of the many other co-operators Dr. Auwers in particular took a large and important share in the work. Accurate places of the comparison stars were needed, and meridian observations of these were made at a large number of places. In the case of Victoria this was supplemented by a heliometer triangulation in order to avoid the various systematic errors that affect meridian observations. The whole discussion, which forms two large volumes (vi. and vii.) of the Cape Annals, is a remarkable record of a thorough and laborious undertaking. It was particularly the kind of investigation to bring out the characteristic qualities of Gill's genius. To plan the work required that perfect understanding of instruments and observations in which he was unrivalled; and to carry it through in its completeness required a dogged persistence which overcame all obstacles, an enthusiasm which shirked nothing, and a power of leadership which inspired all his helpers. There have been other great and successful co-operative schemes since then, but we miss in them the unity of execution which the immense driving-force of Gill's leadership supplied.

The final result gave for the solar parallax $8''.804 \pm 0''.0046$, and in due course this value was adopted (as $8''.80$) in the Ephemerides. In so far as a single investigation can be held to settle so important a constant, the solar parallax was now known with all the accuracy required for the calculations in which it plays a part. Subsequent researches have all tended to confirm Gill's value; the discordant results found by other methods are disappearing, whilst the superiority of the minor planet method has become more and more manifest. In the Eros campaign of 1900-1 the Cape Observatory took no share owing to the northern declination of the planet; but Gill followed the investigation with keen interest and took part in the arrangement of the work. The results from Eros, whilst diminishing the range of uncertainty, so far as accidental errors are concerned, have not appreciably altered the value. Shortly before leaving the Cape, Gill initiated a determination of the same constant by means of spectroscopic observations, the line-of-sight velocity of the Earth relative to a star being measured at opposite seasons, so that the Earth's orbital velocity is found. These observations are now yielding excellent results.

We have seen that his measurements during the observations of Juno at Mauritius convinced Gill of the value of the heliometer

as an instrument of research. In his hands it was capable of remarkable accuracy. The instrument is peculiarly difficult to use, and the number of those who observe with it has always been few. At the time when the 4-inch instrument was constructed for him, the heliometer was usually regarded in England as an exercise for the text-book or the examination question. Even now that its possibilities have been demonstrated it has not been taken up widely. At the present day it is natural to prefer photographic methods, which give equal or perhaps slightly superior accuracy, whilst making far less demands on the observer. Perhaps too the prospect for future progress and development is more obvious in the case of photographic than of heliometer observations. Certainly Gill's success with the heliometer never blinded him to the advantages of the long-focus refractor, and he fully shared the modern tendency to depend more and more on photography. But there is one advantage of the heliometer over the photographic refractor both for solar and stellar parallaxes on which Gill strongly insisted—the heliometer measures are independent of the colour of the object under observation. He maintained, and confirmed by experimental observations, that the skilled observer in making coincidences of the images matches the *colours* and not the most *intense* points of the minute spectrum caused by atmospheric dispersion. This is a refinement obviously impossible in photography, and, for example, it is well known that the doubtful effect of atmospheric dispersion leaves a little uncertainty in the solar parallax deduced from the photographic observations of Eros.

So early as 1872, Gill had begun to plan a series of determinations of stellar parallax with a micrometer attached to his reflector—an investigation which was interrupted by his removal to Dun Echt. On his appointment to the Cape he began to apply his 4-inch heliometer to this work. In this he was joined by Elkin as a volunteer observer, and they set to work on a programme of 9 stars, including Sirius, Canopus, α and β Centauri, with some stars of exceptionally large proper motion. The most important outcome of this work was the parallax of α Centauri, $0''.75$, with a probable error of only a hundredth of a second of arc. The desirability of a larger instrument with some alterations of design soon became apparent, and in 1887 a 7-inch heliometer was constructed at a cost of £2200. With this Gill and Finlay, and afterwards De Sitter, measured 17 stars, including 12 of the brightest in the southern sky, in most cases with a probable error as low as $\pm 0''.01$. These results were of great interest, establishing the remoteness and intense luminosity of some of the brightest stars such as Canopus and Rigel. Whenever they have been put to the test, Gill's values have always been confirmed. Spurious parallaxes are a great bane in stellar investigation, and, at least until recently, few observers have escaped an occasional bad error; but Gill's parallaxes can always be relied on. His general accuracy has been equalled, perhaps a little surpassed, by some modern photographic determinations; but when we compare the sizes of the instruments

—the 40-inch telescope at Yerkes, or the 26-inch at Greenwich, with his 7-inch heliometer—we must marvel at the precision he could obtain. The following table (given by him) will show the comparative accuracy of his work. It gives the probable error of the measured position of a parallax star:—

Cambridge refractor (19'3 feet focus), 4 exposures	$\pm 0^{\circ}048$
Yerkes refractor (63 feet focus), 3 exposures	$\pm 0^{\circ}026$
Heliometer, one complete observation, <i>i.e.</i> 16 pointings	$\pm 0^{\circ}036$

Another application of the heliometer was made in his determination of the elements of Jupiter's satellites and of the mass of Jupiter. The longitudes of the satellites can be found very accurately from the usual observations of eclipses, but the latitudes are more difficult to derive. Heliometer measures had been made before by Bessel and others, but in all cases the satellite had been referred to the limb or centre of the disc. Gill's method was to measure the distances and position-angles of the satellites relative to one another; for, as he had found in his observations of Mars, the best results are only possible when the objects to be measured have no sensible discs. The observations were carried out in 1891. On each night the measures were reduced to a constant scale by referring them to the distance between two standard stars. The absolute distance between the standards was determined by a lengthy comparison with the distances of stars employed in the Victoria triangulation, whose definitive co-ordinates had been found with an accuracy quite exceptional. These observations were the beginning of a very thorough investigation of the whole problem; but the further observations and the discussion of the results were placed by Gill in the hands of younger men, who could give a more undivided attention to the problem. The nature of the investigation required a repetition of the observations at a subsequent date. This was made by the late Bryan Cookson at the Cape in 1901–2. Photographic observations were made concurrently in 1891 and 1902, and again in 1903–4. The whole material thus collected formed an exceedingly valuable source for improving the accuracy of our knowledge of Jupiter's system. The detailed discussion was taken up by De Sitter at Gill's suggestion; he reduced Gill's own observations during a visit to the Cape (1897–9), and worked out the elements and masses derivable from the whole work. It is evident that Gill attached the greatest importance to this work, and, though the later stages were in the charge of other workers, he followed its progress to the minutest detail. His stimulating influence carried it to a successful conclusion—if conclusion it can be called, for in his summary of the work in the *History of the Cape Observatory* he urges the need for an extended programme of future work, and appeals to astronomers to carry it out. His last scientific effort, on the day the fatal illness began, was to write an Introduction to De Sitter's discussion.

Gill's detection of the existence of magnitude equation in

observations of right ascension with the meridian circle was an incidental result of his heliometer observations at Ascension. This definitive discovery of a systematic personality, by which faint stars are regularly observed too late relatively to bright stars, has been of fundamental importance in meridian work. He took great interest in the problem of eliminating this peculiarly difficult source of error by screens and other methods; and it was a source of great satisfaction to him that the travelling-wire micrometer seems to have successfully accomplished this object.

Reference has already been made to Gill's early photographs of the moon. These were, of course, not by any means the first lunar photographs; but in 1882 Gill made a notable advance in celestial photography, by successfully photographing the great comet of that year. Several pictures of this comet had already been obtained, with fixed camera, and the knowledge thus obtained that the light was sufficiently intense encouraged Gill to attempt to obtain images of greater scientific value by guiding the camera in the modern way. He was assisted by Mr. Allis, a local photographer, from whom he borrowed a doublet of $2\frac{1}{2}$ inches aperture and 11 inches focal length. He mounted this doublet on the 6-inch equatorial, which he used as guiding telescope. Excellent representations of the comet were obtained with exposures of from 30 minutes upwards; but—a fact of still greater importance—it was found that, notwithstanding the insignificant size of the apparatus, a great many stars were shown, whose images were well defined over a large field. This suggested the practicability of using similar but more powerful instruments for mapping the sky and for other astronomical purposes to which photography is now applied.

We know now how this result has revolutionised the methods of observational work. Gill led the way in turning the new possibilities to a practical account. The immediate outcome was the Cape Photographic Durchmusterung, started in 1885. The survey covers the region of the sky from the South Pole to Dec. -18° , and is complete so far as photographic magnitude $9^m.2$ (on the C.P.D. scale). A rapid rectilinear Dallmeyer lens of 6 inches aperture and 54 inches focal length was used for the photography. The work was completed in 1890. Very soon after the start Professor Kapteyn's offer was received to devote himself for some years to the arduous labour of the measurement and reduction of the plates, a work for which the Cape Observatory was unable to provide. This is a further instance of Gill's success in attracting for his helpers the men best capable of carrying out the work desired. The association of Gill and Kapteyn, which began now, has proved a most powerful influence in the advance of stellar investigation; and, to quote Gill's own words, "probably the most valuable result of the C.P.D. to science is the fact that it first directed Kapteyn's mind to the study of the problems of cosmical astronomy, and thus led him to the brilliant researches and discoveries with which his name is now and ever will be associated."

We can only mention briefly the other photographic work with which Gill was associated. When the history of the inception of the International Astrographic Chart and Catalogue comes to be written, it will probably be found that much was due to Gill's initiative. It may be difficult to trace whence the first suggestion arose; but at least we know that he was in its councils from the very beginning, and gave his whole-hearted support to the great enterprise. His measuring-machine for photographic plates, designed by him and constructed by Repsold, has been very generally copied in its main features. Another work of great value, which owes much to his counsel and assistance, is the chart of the sky made by the late J. Franklin-Adams. Mr Franklin-Adams, an enthusiastic amateur, who had only recently applied himself to astronomy, came to the Cape at an early stage of the work to photograph the southern hemisphere. It needs little imagination to realise how Gill, by his experienced advice and his insistence on a high standard of quality, helped to make of this the valuable work that it became.

In 1897 the necessary expenditure for a new reversible transit-circle at the Cape was at length sanctioned. Since his first appointment Gill had lost no opportunity of urging the need for an instrument which should be free from the defects which were obvious in the old design. For the determination of fundamental right ascensions and declinations the chief requirements are an extreme stability of the instrument, means of eliminating or determining the flexures of the various parts, and of guarding against the effects of temperature changes both in the instrument and in the surrounding air. The problem of equalising the distribution of temperature was most carefully thought out. The piers were made hollow, covered externally with non-conducting material, and filled with water. The telescope tube was surrounded by a double envelope of copper to minimise the effects of local heating, and the graduated circles were similarly protected by copper discs. Of special interest was Gill's method of obtaining fixed meridian marks for maintaining the azimuth of the transit-circle. Four deep pits, reaching down to the unweathered rock, were constructed underneath the long-focus collimating lenses and the marks respectively; and a simple method was devised by which the apparatus above ground could be readily set in a definite position with respect to the vertical collimating lines of object-glasses fixed in the rock below. So perfect is the stability of these marks that it has been found possible to measure the movement of the north pole over the Earth's surface by the apparent change of azimuth. It is certain that the device will be widely imitated in future.

On his appointment as H.M. Astronomer in 1879, Gill began to consider the question of a geodetic survey of South Africa. His previous experience of such work had been obtained on the occasion of his visit to Mauritius. In connection with the Transit of Venus expeditions of 1874, numerous longitude determinations were made by the various parties of observers; and, indeed, these

geodetic results proved to be the most important outcome of the whole work. Gill's share was a chain of telegraphic longitudes connecting Berlin with Malta, Alexandria, Suez, and Aden. Before returning home, he proceeded to Egypt, in response to an invitation from General Stone, Chief of the Military Staff of the Khedive, in order to measure a base-line for the proposed survey of the country. This work made slow progress at first, as Gill had no trained assistance on which he could rely; but in the end, with the help of Professor Watson, he carried it through satisfactorily. No permanent outcome of this work has survived, for the defining marks of the base-line were afterwards destroyed by Arabs.

It would serve little purpose here to enter into the details of the work which Gill succeeded in accomplishing in South Africa. Besides the more practical uses of an accurate survey, Gill kept ever in view the object of the ultimate measurement of the great arc of the meridian of 105° from the North Cape to Cape Agulhas—the longest measurable arc of the meridian in the world. Colonial and foreign Governments, the Chartered Company, and the scientific societies were all in turn pressed and persuaded. Difficulties of funds, of personnel, of war, interposed obstacles; but there was no resisting Gill. His indomitable persistence always won in the end. Worried ministers would ultimately come to terms with their genial persecutor. Still active in this great cause after retirement from the Cape, he had the satisfaction of getting the last link of the South African chain filled in. The great measured arc along the meridian of 30° E. now extends from Cape Agulhas to within a short distance of Lake Tanganyika, near the boundary of British territory—a length of 24° —at which point it awaits the other chain of triangulation that will some day be pushed down from Egypt.

We have now passed in review the most important of Gill's scientific investigations. To these may be added some miscellaneous contributions, of which we cannot here give any detail. A triangulation by heliometer of the southern circumpolar stars was made under his direction in 1897–1900; but he was not very satisfied with the consistency of the observations. A series of meridian observations of the lunar crater Mösting A, organised by him jointly with Sir William Christie at Greenwich, led to a good determination of the lunar parallax and figure of the Earth. The arrangements for a Catalogue of Zodiacal Stars were placed in his hands by the International Astrographic Congress.

In October 1906 Sir David Gill left the Cape. Owing to ill-health he had anticipated by rather more than a year the date of compulsory retirement. But there were no signs of failing vigour when he returned to England; on the contrary, he plunged into a strenuous life of scientific activity in London. He became President and afterwards Foreign Secretary of the Royal Astronomical Society, President of the British Association at Leicester; and on the Councils of the Royal and Royal Geographical Societies, as *Président d'honneur* of the committee of the Astrographic Chart,

and in numerous other duties, he was a centre of energy and initiative. For several years he worked at his *History and Description of the Cape Observatory*, published in 1913. Amid our sorrow at his death, when still in the full vigour of scientific activity, there is cause for thankfulness that he was spared to complete and to see the reception of this retrospect of the work to which he had devoted his life.

To this record of strenuous work in the cause of science must be added some allusion to the other side of his life. There was an ideal background to his public life in the quiet home—always characteristically Scotch wherever he lived. In Lady Gill he found a sympathiser in all his sacrifices and devotion to astronomy. She did not become an astronomer; but she shared all his desires, and it was ever her care to aid him to fulfil his great calling. She was of Scotch birth like himself, and their home was bright with an indescribable spirit of open-heartedness, which seemed to come from his loved Highlands.

In December 1913 he was seized with double pneumonia, and from the first the gravity of the illness was realised. His magnificent constitution carried him bravely through a long fight with the disease, but heart-failure supervened, and on the morning of January 24 he died peacefully.

There is no need to enumerate the honours conferred on him by the British, French, and German Governments, and by numerous Academies and Universities. Official recognition was generously bestowed; even richer was the tribute of admiration and affection of his world-wide circle of friends.

He was elected a Fellow of the Society 1867 December 13, was President 1909-11, and Foreign Secretary from 1911 till his death. He received the Gold Medal in 1882, and again in 1908.

A. S. E.

EDWIN DURNING-LAWRENCE was born in London on 1837 February 2, and was educated at University College School and at University College. He was called to the Bar in 1867. After some unsuccessful attempts to enter Parliament, he represented Truro as a Unionist from 1895 to 1906. The rank of baronet was conferred upon him in 1898.

The death of Sir Edwin Durning-Lawrence was a severe loss to University College School, of which he was one of the greatest and most generous benefactors. He made many large gifts to the building fund and to other School interests which were in need of help. He was Chairman of the Council for many years, and so keen was his interest in the School, that he never missed a single meeting of the Council, nor even a sub-committee meeting.

In recent years he became widely known as a leading advocate of the view that Bacon was the real author of the works attributed to Shakespeare. His publications include *The Shakespeare Myth* and *The History of Lighting from the Earliest Times*. He was a

man of generous disposition, and contributed liberally to religious and other institutions.

In 1874 he married Edith Jane, youngest daughter of Mr. J. B. Smith, M.P., Stockport; the only child, a son, died in infancy.

Sir Edwin died at his London residence on 1914 April 21.

He was elected a Fellow of the Society 1873 January 10.

GEORGE FRANCIS HARDY was born 1855 December 14, and was educated at a private school of which his father was the principal. In 1871 he became a clerk in the British Empire Mutual Life Office, and in the following years qualified himself for the Institute of Actuaries, of which he was admitted a Fellow in 1880. The routine of an insurance clerkship proved uncongenial to him, and towards the end of 1880 he entered upon actuarial tuition and private practice. He devoted his great mathematical ability to numerous actuarial problems, and attained great eminence in his profession. In 1908 he was elected President of the Institute of Actuaries. From time to time throughout his life he was called upon to advise various Government Departments, and was closely connected with the preparation of our present scheme of National Insurance. In recognition of his distinguished services he was created K.C.B. on 1914 January 1.

Hardy's interest in astronomy commenced at an early age. He first acquired a $2\frac{1}{2}$ -inch telescope, and when between 17 and 18 years old he erected an 8-inch reflector which was equatorially mounted and provided with a revolving dome. In 1874, in a contribution to the *English Mechanic*, he suggested a method of determining the solar parallax by observations, from two distant places, of the occultations of stars by the exterior planets, and pointed out that the accuracy of the results might possibly be greatly increased by the use of the spectroscope. The method, however, is not free from difficulties, and has never been practically tested. His early interest in astronomy was maintained until his death, which occurred on 1914 October 5.

He was elected a Fellow of the Society 1877 February 9.

JASPER NICHOLLS HARRISON was born in 1843 August 6 at Langharne, South Wales. He entered the military profession, and retired with the rank of Captain in the Royal Marine Light Infantry in 1880. He resided at Saling Grove, near Braintree, and at Pendine, Carmarthenshire. He was a Justice of the Peace for Essex and Carmarthenshire, a governor of Felsted School, and a member of many local committees. Captain Harrison was greatly interested in astronomy, but published no papers.

He died at Saling Grove on 1914 March 27, leaving a widow and one daughter.

He was elected a Fellow of the Society on 1882 January 13.

WILLIAM ARTHUR SMITH was born in 1845, and was educated at the Edgbaston Proprietary School. He entered upon a com-

mercial career, and ultimately succeeded his father in business as a merchant. For many years he was a prominent figure in the commercial life of the city of Birmingham. He was deeply interested in charitable and philanthropic affairs, and served on the committee of the Queen's Hospital. He was also a member of the Council of the Midland Institute.

He made a donation of £10 to the Society's Library funds, from which, among other books, a fine copy of *Astronomi Veteres* (Aldus), 1499, was purchased.

He died on 1914 April 11, leaving one son and two daughters.

He was elected a Fellow of the Society on 1897 February 12.

JOHN BENJAMIN STONE was born at Birmingham on 1838 February 9. He was educated at Birmingham Grammar School, and was afterwards in business as a paper manufacturer. He was knighted in 1892, and from 1895 to 1909 he represented East Birmingham in the House of Commons in the Conservative interest. He also took an active part in local affairs, and was five times Mayor of Sutton Coldfield.

His success in business, combined with robust health, enabled him to gratify his inclination for foreign travel and to pursue his favourite hobby of photography. He visited nearly every part of the world, and described and illustrated his travels in a number of books. When in Brazil, in 1893, he joined the British Eclipse Expedition at Ceara, and rendered assistance to the observers by making the exposures with the slit spectrograph. Thenceforward he took a genuine interest in astronomy, and was always well informed with regard to new discoveries and theories. He did not, however, set up an observatory of his own.

Sir Benjamin will be long remembered as an expert amateur photographer. His camera accompanied him on all his travels, and was a familiar object on the Terrace at Westminster, which forms the background of a collection of portraits of national interest. He was especially interested in making pictorial records of customs and ceremonies surviving from ancient times. He was appointed Official Photographer for the Coronation by the King in 1911.

Two volumes entitled *Sir Benjamin Stone's Pictures* (Cassell & Co.) are household works, one illustrating Parliamentary scenes and portraits, the other festivals, ceremonies, and customs. More than 1200 of Sir Benjamin's beautiful prints are stored in the British Museum, and form the nucleus of a collection illustrating a survey of the whole country now in course of making by the National Photographic Record Association, of which he was the founder and first President. His own collection of between twenty and thirty thousand photographs gives some indication of his enthusiasm and amazing industry.

Sir Benjamin died at his residence, Erdington Grange, on 1914 July 2, leaving four sons and two daughters.

Lady Stone died three days after her husband, in ignorance of

his death, and both were buried in the same grave at Sutton Coldfield on July 7.

He was elected a Fellow of the Society 1894 June 8.

THOMAS THORP was born on 1850 October 26, his father being a farmer near Narrow Lane, Besses. Educated first at the Park Lane School, and afterwards at the Grammar School, he then became an apprentice with a Manchester firm of architects and surveyors, taking part during this time in the pioneer work in connection with the town-planning of New Brighton. Quite early in life he showed signs of having inherited the inventive tendencies of his father, devoting much of his time to the devising of practical applications of his scientific knowledge. This tendency to work on practical adaptations of science led him more towards civil and mechanical engineering, and he gradually built up a business for the manufacture of his patented inventions. For thirty years he was the engineer to the Whitefield Local Board and the District Council. He was the first to produce a workable scheme for penny-in-the-slot gas meters; he invented the rotary gas meter, and a tiny device of his for economical regulation of gas delivery has been very widely employed by manufacturers and public authorities.

His devotion to astronomy commenced in his boyhood, and much of his optical equipment was the result of his own labour. He had two observatories: one at his home at Whitefield, the other at a country bungalow at Prestatyn, North Wales. He made and mounted several good telescopes, both reflectors and refractors, and acquired great personal skill in the working of optical glass. He also made several fine objective prisms, one of which has produced excellent results in the hands of Father Cortie at Stonyhurst College. His polarising solar eyepiece and prominence spectroscope have been widely used. Although not strictly a systematic observer, he devoted a good deal of time to work in his observatory. His principal instrument was an 8-inch Cooke equatorial with a photo-visual objective, which, with its spectroscope and attachments for photographic work, has been presented by his family to the Stand Grammar School, near Manchester. The name of Thorp will long be remembered in connection with the beautiful replicas of diffraction gratings which have made the study of spectroscopic astrophysics possible to so many lovers of the science. In addition to putting these on the market at a moderate price, he was most lavish in his generous distribution of them to professional and amateur workers throughout the world. For many years no method for obtaining reproductions of finely ruled diffraction gratings had been known except those published by Lord Rayleigh and M. Izarn, both being photographic methods. Mr. Thorp conceived the brilliant idea of taking a cast of the ruled surface in a transparent medium, and finally decided on a thin solution of celluloid in amyl acetate. This he announced in 1898, and he rapidly improved his process by patient and painstaking experiments on the

materials. His chief difficulties were with regard to quality of solution, dust, and uniformity of setting. The first he overcame by making his own materials, and the others by the simple but ingenious device of setting the films under cover in partial vacuum. For his work in this connection he was awarded the Wilde Premium for Original Research. An interesting application of these replicas was his method of projection in natural colours, by means of three replicas adjusted to diffract the proper colour sensations to the eye. This he demonstrated very successfully at the Dover meeting of the British Association.

An excellent instance of his thoroughness and originality is provided by his attack on the difficult problem of producing diffraction gratings with all the light in one spectrum, instead of being distributed over many orders and a bright central image useless for spectrum work. Rowland indeed had investigated the subject and proved that the problem devolved on the shape of the groove cut by the diamond point, but we have no knowledge of any grating having been definitely made on these lines, although several chance rulings have very nearly fulfilled the condition. Thorp attacked the problem, calculated the shape of the point he wanted, made it, and actually produced a grating by stamping this tool in a metallic surface, the replicas from which were very nearly perfect in the desired property.

His latest desire was to make a ruling machine for himself, and this he devised on quite an original plan, his aim being to eliminate the difficulties which have always arisen in connection with screw-driven machines. In principle his idea was to drive the ruling point by a mercury clepsydra, furnished by a steel cylinder with micrometer valve of the most perfect finish he could command. The machine was well on the way to realisation when he was compelled to give up active work.

He accompanied the Eclipse expeditions to Algiers in 1900, and to Burgos in 1905.

Regarding his personality it is difficult to speak in words. All who knew him were impressed with his delightful companionship, modesty of manner, and constant readiness to help in whatever he was able.

His death occurred at Prestatyn, North Wales, on Saturday, 1914 June 13; he leaves a widow and three sons.

He was elected a Fellow of the Society 1902 April 11.

C. P. B.

SETH CARLO CHANDLER was born at Boston (Mass.) on 1846 September 17, the son of Seth Carlo and Mary (Cheever) Chandler. He was educated in the English High School at Boston, and became an actuary with the Continental Life Insurance Co., taking up his residence in New York. On 1870 October 20 he married Miss Caroline M. Herman of Boston, who, with six daughters, survives him. In 1877 he returned to Boston as consulting actuary for the Union Mutual Life Insurance Co. He moved to

Cambridge (Mass.) in 1881, and to Wellesley Hills (Mass.) in 1904. His business ability was considerable, and his advice carried great weight in the business world. Even in the sad years when his private correspondence, including astronomical matters, was absolutely neglected, his business duties, particularly those relating to many trusteeships which he held, were punctually discharged. He took great interest in buying and putting in order, twenty-five years ago, his grandfather's birthplace, a farm in the central part of Vermont. At times his health suffered from the nervous energy with which he worked, but it had much improved of late years, and his death (on 1913 December 31), after an attack of pneumonia lasting five days only, came as a severe shock to his family and friends.

Chandler's interest in astronomy began at school, where in his last year (1861) he made some calculations for Prof. B. Peirce. He then worked for some time with Dr. B. A. Gould as private assistant, thus laying the foundations of a lifelong friendship. Gould was at this time developing the longitude determinations of the U.S. Coast Survey, and Chandler joined the Survey in 1864; but he declined an invitation in 1868 to accompany Gould to Cordoba, Argentina, and became an actuary, as above mentioned. His astronomical work was resumed when he removed to Cambridge in 1881, and worked for a few years at the Harvard Observatory. His first success was the construction of a new instrument for fundamental observations, the Almucantar, so called because, being floated at a definite angle to the vertical, the telescope sweeps a horizontal circle (for which the Arab name is Al Mucantar). His first trial instrument was of only 1 $\frac{3}{4}$ -inch aperture and 25 inches focal length; but the results obtained with it were of such surprising accuracy that a larger instrument was speedily made, a full description of which (and of the observations extending over a period of thirteen months) forms vol. xvii. of the *Annals of Harvard College Observatory*. These observations led directly to his second success. A curious systematic error was shown by them, one possible explanation of which was that the latitude was slowly changing. Such a hypothesis seemed, however, at that time to have been put out of court; for, on the strength of an investigation by Euler, it was supposed that the position of the Earth's axis could only vary in a period of about 10 months, and all attempts to detect a sensible coefficient for this variation had failed. Hence Chandler felt it more probable that the explanation lay in some other direction. But a few years later Dr. Küstner of Berlin published some observations made just at about the same time as Chandler's (1884-85) fully confirming the hypothetical change of latitude. Chandler thereupon resolved to discuss the matter apart from any prejudice due to Euler's theoretical result, and he soon found, from the discussion of many sets of observations, that there was a variation of latitude, not in 10 months but in 14 months. The discrepancy was disconcerting to the mathematicians, but Newcomb put his finger on its source

by pointing out that Euler's investigation treated the Earth as a rigid body, and that, if allowance were made for elasticity, the period of 10 months would be lengthened. The change to 14 months might thus be regarded as a measure of the Earth's departure from rigidity, and this is now the accepted view. Meanwhile Chandler went steadily ahead with the discussion of huge masses of observations, from modern times back to those of Bradley. He paid a new tribute to Bradley as a wonderful observer (*A.J.*, 513): incidentally he rehabilitated the good fame of Pond, who had been rather under a cloud (*A.J.*, 313), and carried his good offices to our Royal Observatory further by explaining (*A.J.*, 511, and *Mon. Not.*, lxii. p. 122) the behaviour of Airy's Reflex Zenith Tube, which had been a standing puzzle since its erection with high hopes in 1852.

A few words may be quoted from *Mon. Not.*, lxii. p. 123:—

“It is certainly a comfort that the perplexing enigma connected with the Reflex Zenith Tube has finally found its answer, and that the patience of the astronomers who executed this laborious series meets at last an adequate reward of useful result. . . . It scarcely needs to be suggested that [the work] ought properly to extend to all the stars, passing the Greenwich Zenith, bright enough for reflection-observations on a dark sky. This would determine both the aberration and latitude variation, which is not possible with a single star.”

In the light of these remarks of Dr. Chandler, observations with the instrument were resumed at Greenwich, and a large number of stars put on the programme. In 1911 Prof. Eddington discussed the results of eight years' work. He found several sources of instrumental error, and it seemed desirable to change the form of instrument. But Chandler's criticisms had the valuable result of recalling attention to this important investigation.

In all these cases and many others, Chandler showed how the new hypothesis of a variation of latitude would make crooked paths straight. But, meanwhile, he was not without troubles in his own investigations. The period of 14 months detected in 1885 seemed to be replaced in Bradley's time by one of 12 months. The mathematicians again refused to countenance this change. Undismayed, Chandler continued “deliberately to put aside all teachings of theory, because it seemed high time that the facts should be examined by a purely inductive process,” and he ultimately found the means of reconciling observation with theory in the existence of two periods superimposed, an annual and a 14 months' term, one of which gradually overtakes the other. Later he was led to suggest also a 13 months' term (*A.J.*, 522), and again a 15 months' term (*A.J.*, 523). Further observations will probably show that while the first supposition of an annual term and a 14 months' term is a good first approximation, the details are less suitable for definite statement as yet. A fuller account of this latitude investigation will be found in the President's Address on presenting our Medal to Dr. Chandler in 1896. But the original

series of papers in the *Astronomical Journal*, following one another with marvellous rapidity, and yet each representing a great mass of work, are well worth reading by those interested. Incidentally the constant of aberration came under investigation, and Chandler put the value high, say at $20''.52$ (*A.J.*, 529). He was much distressed at the adoption in the Ephemerides, from 1901 onwards, of the value $20''.47$ to accord with the parallax of $8''.80$, declaring that a discrepancy which was probably significant was being unnecessarily obscured. His work on the subject of latitude variation did not, however, end with this series of published papers: he had pursued the matter so much further as to satisfy himself that he had obtained a definitive solution, and it only remained to prepare it for publication. This at any rate he stated to the present writer in 1910. But the serious and continued illness of one of his daughters, who had taken a special interest in his astronomical work, seemed to have paralysed his astronomical energies. His correspondence, outside business matters, as above remarked, lay untouched; the *Astronomical Journal*, of which he had undertaken the editorship, sometimes ceased to appear for protracted intervals; and the investigation of polar motion never appeared. Chandler's papers have been placed in the able hands of Mr. Benjamin Boss, and it is possible that there are sufficient indications of what was in his mind to guide an editor. For the present we have only this hope.

The mere mention of the *Astronomical Journal* suffices to remind us of another side of Chandler's work, as also of close ties of friendship. The editorship of various journals has had remarkable influences in astronomy. Prof. E. C. Pickering has more than once remarked that the Astronomical and Astrophysical Society of America originated in the gathering of the editors of the *Astrophysical Journal*. The *Astronomical Journal* cemented close friendships among its editors. Founded by Gould in 1849, it ran through six volumes of twenty-four numbers each, and then ceased abruptly in 1861 with the American Civil War. Chandler's name does not appear in these first six volumes: he was only a school-boy. But when, on Gould's return to the States, the Journal was restarted in its old shape in 1886, Chandler contributed no less than twenty papers to the first volume. They are chiefly on comets and variables. He was an enthusiastic computer of cometary orbits, and towards the end of this first volume is an account of the "Science Observer Code" which was instituted to give telegraphic information of the orbit and ephemeris of a new comet as soon as possible. Apparently John Ritchie had started the idea in 1879, but Chandler must have entered into it very early, and the code published in the *Science Observer* (vol. iii., 1881 Aug. 1) bore the joint names. In the second volume of the revived Journal appears Chandler's First Catalogue of Variable Stars, as also two papers on those periodic departures from a uniform period to which he paid such unremitting attention in later years. His First Catalogue was followed by supplements, and in course of time

by a Second (*A.J.*, 300), a Third (*A.J.*, 379) and a Revised Third (*A.J.*, 553) Catalogue; each representing great labour. There came a time when he felt unequal to further work in this field, and it was handed over to a German Committee. But Chandler's Catalogues form a landmark in the history of the subject.

On Gould's death in 1897, Chandler took over the editorship of the *Journal*, as an act of piety to his lost friend. Gould left a small endowment for it, which Chandler often supplemented from his private means; for a journal of that kind is somewhat of a luxury. After his activities suffered the blow above mentioned, he handed over the editorship to another close friend, Lewis Boss, whose papers on the places of fundamental stars had illuminated the pages as brightly as Chandler's on variation of latitude. Although the *Journal* again lost its editor in 1912, it is still in the capable hands of his son.

It would unduly prolong this notice to follow the whole of Chandler's work: but mention must be made of his identification of Comet *d* 1889 with Lexell's Comet of 1770; and of his recovery of the little planet Eros from plates taken previous to its discovery in 1898. Orbits of DQ (or "Pluto," as some called it at first), computed from the plates of 1898, suffered from uncertainty as to the mean motion, which rendered the position in 1894 too vague to identify the object. Chandler had the happy thought of searching the plates of 1896, when the planet was very faint; he succeeded in finding it, and, with an improved mean motion, quickly traced it on the 1894 plates. His delight in this success does not appear in the sober statement (in *A.J.*, 452); but it bubbles over in a letter to the present writer, dated on Christmas day 1898, equal appreciation being shown of Boss's recent paper on the southern zone — 20° (*A.J.*, 448–50). The successful outcome of a piece of work was a very keen pleasure to him; and in pursuit of it he often worked under an obvious stress of excitement, one familiar feature of which was that he could not wait to write down the logarithms of a pair of numbers to be multiplied, but added them in his head and found the product directly.

This keenness in delight, and also in impatience, was characteristic of him throughout. He loved the music of certain composers — Beethoven, Gounod, and Verdi; but could hardly stay in the room if Debussy, or even Brahms, were played. He read very fast, and could read anything except the modern novel. He spent much time in Vermont, designing and constructing beautiful little sailing boats of novel type, and claimed that long before a certain "America Cup" defender was launched, he had sailed her exact model in his little pond. He was well versed in the lore of magic and was himself a good conjurer; but the real object of these pursuits was the confounding of those who showed leanings to spiritualistic beliefs. One of his idiosyncrasies is made plain by the following remark: "I used to say that it was a mark of aristocracy not to own an automobile; it is more than that now: it is a mark of respectability."

Chandler was elected a Foreign Associate of this Society in

1889 Nov. 8. In 1895 he received the Watson Medal of the National Academy of Sciences, and in 1896 our Gold Medal. He received the degree of LL.D. from De Pauw in 1891. He was a member of the U.S. National Academy; and a Fellow of the American Association, of which he was Vice-President in 1886.

For a great many years he was an influential member of the Bache Fund Committee of the National Academy, and of the Gould Fund Committee of the American Academy.

H. H. T.

NILS CHRISTOFFER DUNÉR was born at Billeberga, a village in South Sweden, on 1839 May 21. He entered the University of Lund in 1855, and took the degree of Doctor of Philosophy in 1862. His connection with the Lund Observatory began in 1858, and he became a member of the regular staff of that institution in 1864. He remained at Lund until 1888, when he was appointed director of the Observatory, and Professor of Astronomy in the University of Upsala. After his retirement in 1909 he continued to reside at Upsala until September last, when he removed to Stockholm. He died at Stockholm on 1914 November 10, soon after his return from a journey to Helgum in North Sweden, where he went to observe the total eclipse of the Sun in August.

Dunér was an active and distinguished worker in many departments of astronomy. During the period 1867 to 1875, with the 10-inch refractor at Lund, he made 2679 measures of double stars, the results of which were published in his well-known memoir, *Mesures micrométriques d'étoiles doubles faites à l'Observatoire de Lund* (1876). This work at once placed Dunér in the front rank of double-star observers and computers.

In 1878 Dunér was attracted by the subject of stellar spectra, and notwithstanding the moderate aperture of the Lund refractor, he made a particularly valuable series of observations of the red stars, most of which are faint. His classical memoir, *Sur les étoiles à spectres de la troisième classe* (1884), gives details of the visual spectra of 352 stars, of which 297 belong to Vogel's Type III. *a* (Secchi's Type III.) and 55 to Class III. *b* (Secchi's Type IV.), the former being characterised by bands now known to be due to titanium oxide, and the latter by bands of carbon and cyanogen. The relative positions of these two classes of stars in the scheme of celestial evolution is still a subject of discussion. Spectra intermediate between the two classes are not clearly represented in the heavens, and Dunér himself adopted Vogel's view, that they represent alternative and not successive forms following the decline of stars of the solar or second type. Dunér's observations were discussed in great detail by Sir Norman Lockyer in his *Meteoritic Hypothesis*, where it is argued that there must be stars of increasing as well as of decreasing temperature, and that the true place of the third-type stars is on the ascending arm of the "temperature curve," while the fourth-type stars occupy the lowest division of the descending branch, in direct succession to

the stars of the second type. This view has received some support quite recently by the investigations of Professor H. N. Russell, but the question cannot yet be considered to be finally decided.

Dunér returned to the red stars in 1893, when the Upsala Observatory became possessed of a refractor of 36 cm. aperture, in combination with a photographic telescope of 33 cm. aperture. With characteristic thoroughness he planned to re-examine the stars which he had previously observed at Lund and to include the discoveries which had been made in the interval which had elapsed since the publication of his first memoir. It seemed to him that, so far as possible, all such stars in the northern heavens should be examined by one and the same observer, and it is evident that such a series of observations would have a special value for purposes of classification. In 1899 (*Astrophys. Jour.*, vol. ix. p. 119) he published an account of his further observations of 54 fourth type stars, and the result which he regarded as of first importance was the detection of bright lines in some of the spectra, apparently in confirmation of the photographic observations of Professor Hale. It can scarcely yet be considered established, however, that these supposed bright lines are not merely interspaces between groups of dark lines or bands.

Perhaps the most celebrated work by Dunér was that on the Sun's rotation, carried out at Lund with a powerful Rowland grating spectroscope which he specially designed for the purpose. The spectroscopic method of determining the peripheral velocity, and thence the period of the Sun's rotation, had previously been employed by Vogel and Young, but Dunér's work had the special merit of extending the observations to latitude 75° , far outside the Sun-spot zones, where the observations become especially delicate. Many difficulties were overcome by Dunér's method of observation, which consisted of measuring the displacements of two iron lines at $6301\cdot72$, $6302\cdot72$, with respect to two neighbouring telluric lines at $6302\cdot21$, $6302\cdot97$; being produced by absorption in our own atmosphere, the latter, of course, remain undisturbed by the Sun's rotation. The result was to show that the polar retardation already known from observations of spots, was continued to high latitudes, and that the equatorial period of about 25 days was increased to something like $38\frac{1}{2}$ days in the highest latitudes. The careful record of this work given in Dunér's memoir, *Recherches sur la rotation du Soleil*, published in 1891, establishes complete confidence in the results, and it is not surprising to find that the main conclusions were confirmed by another series of observations made at Upsala fifteen years later. A great deal of interesting work in this direction has since been carried on, by photographic methods, by an organised body of observers acting under a committee of the International Solar Union, of which Dunér was for a time chairman. Dunér's pioneer contributions to the investigation will long occupy an honoured place as a term of comparison.

Dunér also made notable contributions to our knowledge of variable stars. He discovered the variability of S Aurigæ,

V Boötis, V Coronæ, and W Herculis, and his name will be especially associated with his investigations of the short-period variables Y Cygni and Z Herculis discovered by Chandler. In the case of Y Cygni, his observations led him to the interesting conclusion that the system consists of two components of equal size and brightness which produce the light-variations by their mutual occultations; the eccentricity of the orbit is given by Dunér as 0.145, and the major axis as eight times the radius of the stars, while the period of an anomalistic revolution is 2.996933 days. The second star, Z Herculis, he regarded as a connecting link between Y Cygni and variables of the Algol class. In this case he found that the phenomena could be explained by supposing that while the two components are of equal diameters, one is twice as bright as the other; he calculated the eccentricity of the orbit to be 0.2475, the semi-major axis six times the diameter of the stars, and the period of revolution 3 days 23 hours 48 mins. 30 secs. These conclusions cannot, of course, be tested by direct observations of the component stars, as they are far too close to be separated, but confirmation by spectroscopic determinations of the motions of the stars may yet be possible.

Dunér accompanied Nordenskiöld on his expeditions to Spitzbergen in 1861 and 1864, and gave special attention to the question of measuring an arc of meridian in high latitudes. He did much to promote this undertaking, which was subsequently carried out successfully through the combined efforts of Sweden and Russia.

Dunér was greatly esteemed by his pupils and fellow-workers, and was warmly welcomed at astronomical gatherings at home and abroad. He was one of the founder members of the Astronomische Gesellschaft, and took part in the Congress for organising the work on the International Chart of the Heavens.

The Rumford Medal was awarded to Dunér by the Royal Society in 1892, and numerous other distinctions were conferred upon him by various academies and learned societies.

He was elected an Associate of the Society on 1889 November 8.

A. F.

GEORGE WILLIAM HILL was born at New York on 1838 March 3. His father had come from England in 1808, while his mother was descended from one of the original Huguenot colonists. Early in his life his parents removed to West Nyack, N.Y., and there, in a quiet country home, Hill spent his boyhood. At the age of seventeen he went to Rutgers College, New Brunswick, N.J., where, under Dr. Strong, he received his introduction to the works of Euler, Laplace, Lagrange, and the other great writers on dynamical astronomy. The knowledge he obtained there had the greatest influence on his subsequent work. From Rutgers, Hill proceeded in 1859 to Cambridge, Mass., to continue his studies. Soon he started his original work. For an essay extending Laplace's theory of the configuration of the Earth he was awarded a prize offered by the *Mathematical Monthly*. This essay served as an introduction to Runkle,

the editor, who was superintendent of the *American Nautical Almanac* Office. Early in 1861 Hill was offered, and accepted, a post in the office, and there he laboured for thirty years to the great advantage of mathematical astronomy.

In his early years at the *Nautical Almanac* Office, Hill wrote a few papers dealing with problems of general mathematical interest, but he soon confined his attention to purely astronomical subjects. In one of several papers written for the purpose of facilitating astronomical computation, he gave a very full discussion of the derivation and reduction of star places. But more and more he turned towards dynamical astronomy. The determination of orbits was one of his favourite subjects. In particular we may mention a rigorous discussion of all the observations of the great comet of 1858, and a determination of the most probable orbit. The most important part of Hill's early work is in connection with the planet Venus. In view of the transit of 1874 he determined corrections to the elements of the orbit and discussed in great detail the phenomena of the transit.

But it was not merely the application of previously existing theories that engaged Hill's attention. Even from the beginning of his career he was eagerly inquiring after new methods for attacking the old problems and for simplifying the numerical calculations. The rate of discovery of new minor planets was increasing so rapidly that it appeared that the calculators would not be able to keep pace with the discoverers, and that many new planets would be discovered only to be lost. Hill was thus led to write several papers for the rapid calculation of approximate orbits. These orbits would be sufficiently accurate for following the body till a rigorous orbit could be worked out. But Hill was not the man to be long content with approximate orbits, and he was soon at work on perturbations. This led him to the masses of the planets, a subject to which he devoted a great deal of attention throughout his life. The planet which produces the greatest effect on the minor planets is Jupiter, and Hill gave tables for calculating certain long inequalities produced by it on all minor planets with a daily mean motion between $550''$ and $650''$. Observations of these planets over a sufficient interval of time will yield a very accurate value of the mass of Jupiter.

In 1877 and 1878 there appeared the work by which Hill is best known, and which constitutes his most original contribution to our knowledge of celestial mechanics—a new method of dealing with the Moon's motion. For some years the world failed to recognise the value of Hill's work—so novel was the method and so unknown the author. It is true that early in the history of the lunar problem Newton and Euler had used methods resembling that employed by Hill. But their work had never been employed in any of the serious attempts to solve the problem of the Moon's motion, and, latterly, astronomers had settled more or less into a groove as to the best line of attack. Successive attempts had led to more and more accurate results as the quantities neglected became

smaller and smaller, but the formulæ were rapidly tending to become unmanageable on account of the enormous number of terms involved and the greater labour involved in calculating each new term. Astronomers were more inclined to look with amazement at what had already been accomplished (or, perhaps, to contemplate adding more terms to the already existing series) than to think of a new theory, when Hill's memoirs appeared. The entire treatment of the problem was altered. Instead of polar co-ordinates referred to fixed axes, rectangular co-ordinates referred to moving axes were introduced. By this means Hill obtained the differential equations in a simple algebraic form, very suitable for solution in infinite series. The use of a new parameter greatly increased the convergency of the series. The new method then led to the use of the "variational curve" as an orbit of reference. All previous lunar theorists had used an ellipse for this purpose. The characteristic of the "variational curve" which makes it so useful is that it contains a most important part of the solar perturbation, known as the "variation." One of the great difficulties which had been met in the older theories was due to the fact that the lunar perigee had a continuous motion, so that a fixed ellipse could not be found which approximated to the actual orbit of the Moon for any length of time. In the new theory this gave no difficulty. The value of Hill's method has been acknowledged throughout the world, but although Hill wrote sufficient to prove its usefulness, he never had the time to elaborate a lunar theory. Nevertheless, his ideas have been put to practical use. The great task of developing and applying the method has been successfully undertaken by Professor E. W. Brown. The new theory has been completed, and the necessary tables are being formed.

The memoirs in which Hill announced his new method, besides being of the greatest importance as having led to a new lunar theory, deserve detailed attention on other accounts. The "variational curve," which is fundamental to the theory, is a rigorous solution of the problem presented by the differential equations of motion when the eccentricities, the inclination, and the parallax, vanish. The actual motion of the Moon is obtained as the result of "free" and "forced" oscillations about the "variational curve." The "variational curve" is the first* example we have of a periodic curve, which is a rigorous solution of the problem of three bodies. It is the starting-point of a general theory of periodic orbits which has been developed by Poincaré, Darwin, Brown, Moulton, and others. The importance of periodic orbits is due to the fact that they are valid for all time. No known orbit is periodic, but our hopes of obtaining lunar and planetary theories which will be accurate for very long intervals of time are intimately connected with periodic orbits.

In regions of pure mathematics, also, Hill's memoirs on the lunar theory have given rise to important advances. In discussing

* Unless we consider the very special case of Lagrange's three particles as such.

the eccentricity of the Moon's orbit, Hill by a series of skilful transformations made his results depend on the solution of a differential equation of the form

$$\frac{d^2x}{dt^2} + (\Theta_0 + 2\Theta_1 \cos t + 2\Theta_2 \cos 2t + \dots)x = 0,$$

where Θ_1 , Θ_2 , are a series of decreasing small quantities. This equation is of frequent occurrence in physical problems, and in connection with these has been treated by Lord Rayleigh and others. Even before Hill's work, the equation had been obtained by Adams* in connection with the motion of the Moon's node, in which problem it arises naturally. Adams had actually solved the equation with considerable accuracy in much the same way as Hill. But Adams' work was unpublished till after Hill's appeared. Hill's discussion shows the extraordinary originality of his mathematical genius. The solution involves the use of an infinite determinant—an entirely new mathematical idea. In all problems involving an infinite number of terms the utmost care has to be taken if gross errors are to be avoided. In the case of the infinite determinant the danger is particularly great. But Hill successfully overcame all the difficulties and obtained a result of great analytical beauty which enabled him to calculate the motion of the lunar perigee with a degree of accuracy far surpassing anything previously obtained.

The invention of this new method is not Hill's only contribution to lunar theory. At various times throughout his long life he wrote important papers dealing with definite branches of the theory, and, particularly, extensions of Delaunay's theory. As is well known, Delaunay did not quite complete his theory: at the time of his death there were several sources of perturbation still to be considered. Hill always expressed the greatest admiration for Delaunay's work and spent a great deal of time in calculating the outstanding perturbations. In one of his papers he calculated all the perturbations due to the Earth's ellipticity. Hill shows his usual thoroughness in this paper by determining for himself the value of the constant which enters. This entailed an elaborate discussion of numerous pendulum experiments. In other papers dealing with the Moon, Hill dealt with perturbations produced by planets, and inequalities due to the motion of the ecliptic.

Turning again to Hill's work on planetary theory we find a memoir "On Gauss's Method of Computing Secular Perturbations, with an Application to the Action of Venus on Mercury." This is a rediscussion of a celebrated investigation of Gauss's, in which the formulæ are obtained in a very simple manner. The object of this paper was to emphasise the importance of Gauss's original

* We might mention here that Adams was probably alone for several years in fully appreciating Hill's work. It was largely due to Adams' unstinted praise that Hill's work was recognised as soon as it was. The fact is the more remarkable as several of Hill's ideas—*e.g.* that of the infinite determinant—had already been employed, but not published, by Adams.

memoir and to reduce the formulæ to the form best adapted for practical requirements.

Hill had at various times been engaged in work connected with Jupiter and Saturn. The appointment of Newcomb to the directorship of the *Nautical Almanac* Office in 1877 led to his definitely taking up the problem presented by the two great planets. Newcomb* had conceived the idea of revising the tables of all the planets on a uniform basis. The most difficult part was connected with Jupiter and Saturn, and Newcomb left it entirely to Hill. These two planets had always given trouble. The cause of that trouble had been found by Laplace to lie in the fact that five periods of Jupiter are very nearly equal to two of Saturn. Laplace, Pontécoulant, and Plana had not obtained the required degree of accuracy, as they had not an adequate method for obtaining the perturbations of the second order. Such a method was subsequently invented by Hansen, but he had left his work on Jupiter and Saturn unfinished in order to apply his method to the Moon. Hill concluded that Hansen's method, suitably developed to give perturbations of still higher orders, would suffice for his purpose. This was, to use his own words, "to form theories of Jupiter and Saturn which would be practically serviceable for a space of three hundred years on each side of the central epoch taken near the centre of gravity of all the times of observation: theories whose errors in this interval would simply result, not from neglected terms in the developments, but from the unavoidable imperfections in the values of the arbitrary constants and the masses, adopted from the indications of observation." At this work Hill laboured for nearly fifteen years. All the original calculations he made himself, and although Newcomb pressed him to accept assistance, he only consented in so far as duplication was concerned. The resulting tables, which are as accurate as any we possess, have been used in the construction of all the great national ephemerides (except the *Conn. des Temps*) since 1900.

Immediately after he had completed this work, Hill retired from the *Nautical Almanac*, to quote the words of Newcomb, "doubtless feeling, as well he might, that he had done his whole duty to science and the government." It was only from his official duties, however, that he retired, for he continued to work at many problems connected with the theory of perturbations. For a short time, indeed, he undertook to lecture on celestial dynamics at Columbia University, but he preferred to live quietly at his old country home. There he worked continuously to the very end of his life, writing many papers of importance. These papers cover a very wide field, and it is impossible to do justice to them all. All questions involving the fundamental constants of the solar system received his attention. He extended his researches in lunar theory; he calcu-

* Leverrier, also, much earlier had been at work forming new theories of all the planets. The work at this time was nearly complete except for Jupiter and Saturn. The theories of these planets only appeared some time after Hill had his work well in hand.

lated the masses of several planets; and he wrote new papers on the theories of Jupiter and Saturn. A comparison of his new tables for these planets with the most recent observations showed that his theory was sensibly correct. In his later years, however, his mind tended towards those methods of calculating general perturbations which seemed hopeful of giving results valid for longer intervals of time than the ordinary theories afforded. We thus find memoirs on periodic orbits, intermediary orbits, and periphlegmatic orbits. The researches of Poincaré and Gylden therefore received a close examination by him. He expressed high admiration for Poincaré's work on periodic orbits, and believed that it would lead to results still more valuable than those already obtained. Gylden attempted by quite different methods from Poincaré to obtain theories suitable for indefinitely long intervals of time. He undertook his researches from a much more practical point of view than Poincaré, and on that account his work was specially attractive to Hill. Unfortunately Gylden had set himself the tremendous task of dealing with all the eight great planets at once, and this together with his early death prevented him from getting anything completed. Hill believed that by taking more restricted problems results of value could be obtained in a comparatively short time. In particular he derived results for Jupiter and Saturn when the inclination of their orbits is neglected and various constants are assumed known. The difference between the actual and ideal cases is calculable. In other papers he dealt with other aspects of Gylden's work. His last paper was published in 1914 January in the *Astronomical Journal*, of which he was an associate editor.

It is difficult to find such another man as Hill in the whole history of science. Although holding only a humble post in the *Nautical Almanac* Office, he lived happily in the liberty it afforded him, and never sought to improve his material position. All he asked was peace and freedom to prosecute his work. Newcomb did his best to secure official recognition for his illustrious assistant, but Hill seemed to take little interest in the matter. The post he occupied, happily, did not prevent his getting due scientific recognition. Newcomb's words put the situation very plainly: "Here was perhaps the greatest living master in the highest and most difficult branch of astronomy, winning world-wide recognition for his country in the science, and receiving the salary of a department clerk." Europe, as well as his own country, bestowed on him the highest scientific honours. He was awarded our Gold Medal in 1887. The Royal Society elected him a foreign member in 1902, and awarded him the Copley Medal in 1909. When he visited this country in 1892, Cambridge gave him an honorary degree. France elected him a corresponding member of its Institute. Mathematicians throughout the world have declared that they found inspiration in his work. He was President of the American Mathematical Society, 1894-96. Four large quarto volumes of his collected works were published by the Carnegie Institution

of Washington, 1905-07. His later works could form a fifth volume.

Hill stands in the foremost ranks of dynamical astronomers. Few have the time or inclination to read his works. A glance at the volumes, particularly that on Jupiter and Saturn, will show their magnitude. The fact that his tables have been generally accepted as the best is proof of their accuracy. Poincaré's praise and the labour devoted by Brown and others to the development of his lunar theory are the best proofs of its value. But only those who actually read his works can form a true estimate of his greatness. Even his earliest papers show that he had a firm grasp of the whole field of celestial dynamics as it had been presented by the great masters of the past. Almost everyone who studies carefully any of the great works will be fascinated by them. Celestial dynamics seemed to enter into the soul of Hill. Yet his knowledge of what had already been done did not tie him down to the old methods. His mind seems to have been so singularly clear that he could comprehend a whole theory as a single thought. It was the clearness of his intellect together with the highest mathematical genius which enabled him to do so much. To him mathematics was the handmaid of astronomy. Although capable of the highest mathematical research, he did not aim so much at the formation of elegant formulæ as at the determination of the actual quantities of which dynamical astronomy stands in need. His new method for forming a lunar theory will probably remain the greatest monument to his fame, but the most marked characteristic of his work is its eminently practical character.

He died at West Nyack 1914 April 16.

He was elected an Associate 1878 November 8.

J. J.

EDWARD SINGLETON HOLDEN was born at St. Louis, Missouri, on 1846 November 5. He was a direct descendant of Justinian Holden of the county of Kent, who went to America in 1636. Professor Holden received his early education about 1854 at some private schools at Cambridge, Mass., and it was at this time that he learnt his first lessons in astronomy from his cousin, Professor George Philip Bond, then Director of Harvard College Observatory. In 1860 Holden entered the preparatory Academy of Washington University, and after two years he passed into the scientific school. He soon attracted the attention of Professor Chauvenet, then Chancellor of the University, with whom in 1864 he resided, and he prosecuted his studies directly under Chauvenet, whose daughter he subsequently married. In 1866 he assisted Dr. Benjamin Apthorp Gould in an investigation of the military and anthropological statistics of American soldiers. In that year he took his degree as B.S. in the scientific school. In the same year he entered the Military Academy at West Point, where he continued his mathematical studies. In 1870 he was appointed second lieutenant of artillery, and in the following year he returned to West Point as assistant Professor of Natural and Experimental

Philosophy, after which he became instructor in practical military engineering.

In 1873 Holden resigned his commission in the army on his appointment as Professor of Mathematics in the United States Navy, and proceeded to the Washington Naval Observatory, where he became assistant to Professor Harkness, who was in charge of the Transit-Circle. In November of the same year, on the completion of the 26-inch equatorial of that observatory, he was transferred to assist Professor Newcomb, who had charge of that instrument. He remained in this position for six years, first with Professor Newcomb, and afterwards with Professor Hall. In 1876 Holden came to London, under instructions, to report upon the Loan collection of scientific instruments at South Kensington. In his report he gives a full account of the system of time-signals, and of the methods of testing chronometers in use in foreign countries. In this year he accompanied the writer in a yachting tour round Scotland, and then took advantage of his being in the north to visit the late Mr. R. S. Newall's observatory at Gateshead, for the purpose of comparing the 25-inch telescope there erected with the Washington equatorial. Bad weather allowed him to examine only one or two stars.

In 1881 February, on the vacancy caused by the death of Professor J. C. Watson, Holden accepted the position of Professor of Astronomy in the University of Wisconsin and Director of the Washburn Observatory, which he held for five years. During this period, as consulting astronomer to the Lick Trustees, he made several visits to Mount Hamilton. In 1883 Professor Holden conducted the Government expedition to Caroline Island to observe the total eclipse of the Sun on May 6 in that year. The European parties which united with him there included Janssen, Trouvelot, Tacchini, Palisa, and Ray Woods.

On 1886 January 1 Holden resigned his position at Madison on accepting the appointments of President of the University of California, and Director of the Lick Observatory.

The establishment of the Lick Observatory was an event of capital importance in astronomy, and one with which Professor Holden was closely connected. In 1874, some two years before his death, James Lick placed in the hands of Trustees the sum of \$700,000 to provide a telescope more powerful than any yet made, and a suitable observatory connected therewith. Various suggestions were made as to the most suitable site, and it was in 1874 that Professor Holden proposed that Mount Hamilton was the most promising position. Accordingly, in 1879 Professor Burnham was invited by the Lick Trustees to transport his six-inch telescope to Mount Hamilton, and to observe double stars there, so that he might test the quality of the vision and compare it with that of Chicago and Washington. Burnham's thorough and exhaustive report was based on observations made in August, September, and part of October. His conclusions are thus given: "So far as one may judge from the time during which these observations were

made, there can be no doubt that Mount Hamilton offers advantages superior to those found at any point where a permanent observatory has been established. The remarkable steadiness of the air, and the continued succession of nights of almost perfect definition, are conditions not to be hoped for in any place with which I am acquainted, and, judging from the published reports of the various observatories, are not to be met with elsewhere. The ease with which difficult objects can be seen almost down to the horizon will be apparent from the southern declination of many of the new double stars. Close pairs can be observed at least down to 43° south declination" (86° Z.D.). More recently Professor Keeler showed that in winter time the vision is not specially better than at lower elevations. The secret of the steady seeing at Mount Hamilton appears to lie in the coast fogs. These roll in from the sea every afternoon in summer, rising 1500 to 2000 feet. They cover the hot valley and keep the radiation from it shut in. There are no fogs in the day time and few in the winter.

The plans of the observatory were sketched out in 1874 by Professor Holden and Professor Newcomb, and these were practically those eventually carried out in 1879. As far back as 1877, Holden had been designated as the first Director of the Lick Observatory. During his sojourn at Madison he made several visits to Mount Hamilton to superintend the erection of the Repsold Meridian Circle, and to observe the Transit of Mercury.

On 1886 January 1, on the completion of the observatory, he took charge as Director. He occupied this position for twelve years until 1897 December 31, when, on account of some internal dissensions in the observatory, he resigned the appointment.

During the period of his Directorship of the Lick Observatory, Holden had the valuable assistance, among others, of Burnham, Keeler, Barnard, Schaeberle, and Campbell. Upon this point the remarks of Professor Newcomb may be quoted. He says: "One fact is indisputable, and that is the wonderful success of the director in selecting young men who were to make the institution famous by their abilities and industry. If the highest problem of administration is to select the right men, the new director certainly mastered it." He further says: "I know of no example in the world in which young men, most of whom were beginners, attained such success as did those whom Holden collected around him. The names of Barnard, Campbell, and Schaeberle immediately became well known in astronomy, owing to the excellence of their work. Burnham was, of course, no beginner, being already well known; nor was Keeler, who was also on the staff. In a few years commenced the epoch-making work of Campbell, in the most refined and difficult problem of observational astronomy—that of the measurement of the motion of stars to or from us. Through the application of photography and minute attention to details, this work of the Lick Observatory almost immediately gained a position of prominence, which it maintains to the present day."

Professor Campbell has recorded that "the evidences of

Professor Holden's organising ability and energy are written all over the Lick Observatory. His own scientific work there related principally to the photography of the Moon. He made occasional observations of the nebulae and of the planets, but his extensive administration duties did not leave him much time for personal research."

Professor Holden was an enthusiastic astronomer, and took up many branches of research. He contributed nearly one hundred papers to different scientific journals and transactions. These include papers on the satellites of Uranus and Neptune; on measurements and the inclination of Saturn's ring; an investigation of the Sun's diameter in collaboration with Professor Newcomb; many papers on nebulae, including a very complete index-catalogue of books and memoirs on nebulae and clusters, besides papers on comets, double stars, and stellar distribution. While at Washington he published an extensive monograph on the central parts of the nebula in Orion. The object of this work was "to leave such measures and descriptions of the brightest parts of the nebula of Orion as shall enable another person observing in after years with the same telescope, under like conditions, to say with certainty whether or no changes have occurred in those parts of this nebula." This work was a very thorough investigation, with reproductions of all known drawings of the nebula, including a discussion of the first photograph of the nebula, which was made by Dr Henry Draper. While at the Washburn Observatory Holden discovered many red stars, and he observed the 303 stars of Auwers' fundamental catalogue; and in collaboration with Professor Hagen he prepared and published a catalogue of 1001 southern stars on the basis of Tacchini's observations. In this period Holden was commissioned to take charge of the American expedition to Caroline Island to observe the total eclipse of the Sun on 1883 May 6. The report that he prepared on this occasion is perhaps the most complete that has yet appeared on any eclipse expedition. At this eclipse Holden devoted himself to a search for the inter-Mercurial planets which had been supposed to have been observed by Watson and Swift at the eclipse of 1878. With more adequate instrumental means, using the six-inch telescope formerly belonging to Burnham, he was able to disprove the existence of any such bodies. In 1879, Newcomb and Holden published an excellent Manual of Astronomy for schools and colleges, which ran through several editions. Holden also wrote, in 1881, an interesting book on the Life and Works of Sir William Herschel. In one of the volumes of the Washburn Observatory he has given 1088 of Sir William Herschel's star gauges reduced to 1860; and in conjunction with Professor Hastings he published a synopsis of the scientific writings of Sir William Herschel.

Holden's astronomical career terminated with his departure from the Lick Observatory. In 1901 he was appointed by the Minister of War to the post of Librarian to the Military Academy of West Point. This position was very congenial to him, and he

laboured unceasingly to make the library meet the needs of every instructor and every cadet. To this end he prepared complete bibliographies on every military subject. His activity in the library continued up to the time of his death on 1914 March 16.

Holden had great versatility and devoted himself to many subjects. In 1881 he published *Studies in Central American Picture Writing*, being a memoir on the Maya hieroglyphs of Yucatan; in 1898, a *Catalogue of Earthquakes on the Pacific Coast, from 1769 to 1897*. He wrote on *The Number of Words used in Speaking and Writing*, on *The Bastion System of Fortifications*, and on *The Cipher Despatches relating to the Election in 1876 of the President of the United States*. In 1895 he published a most interesting *History of the Mogul Emperors of Hindustan*, containing copies of several miniatures of those sovereigns.

Holden had an engaging personality. He was well read in literature generally, and his tastes were refined and cultured. He was a charming letter-writer. His lengthy correspondence with the writer, extending over twenty years, is marked by unvarying appreciation of the colleagues with whom he worked. As a teacher he had the rare faculty of arousing the enthusiasm of his pupils. The words of one of his colleagues at the Lick Observatory may fittingly be quoted: "His social abilities were of a very high order. His conversation was entertaining to the point of brilliancy. His hearers did not always agree with his point of view, which he defended with vigour and skill, but no one could be found to deny that Professor Holden had made the subject seem alive. His lamented death puts former associates into the reminiscent mood which accompanies the passing of a remarkably interesting man."

Professor Holden received many distinctions. From the Wisconsin and Columbia Universities he received the degree of LL.D.; the degree of Sc.D. from the University of the Pacific, and that of Litt.D. from Fordham College. He was elected a member of the National Academy of Sciences in 1885, and he was at different times a member of the Board of Visitors of the U.S. Military and Naval Academies. He was a Knight Commander of the Ernestine Order of Saxony, and a Knight of the Royal Order of the Dannebrog; and he also received the Order of Bolivar.

He was elected an Associate of this Society 1884 November 14.

E. B. K.

PROCEEDINGS OF OBSERVATORIES.

The following reports of the proceedings of Observatories during the past year have been received from the Directors of the several Observatories, who are alone responsible for the same.

Royal Observatory, Greenwich.
(*Director, Sir F. W. Dyson, Astronomer Royal.*)

Transit Circle.—15,450 observations have been obtained. The Sun has been observed on 182 days, and the Moon on 110 days. Reflexion observations of stars have been made on 122 nights.

The observations for the catalogue of stars down to 9^m.0 on the B.D. scale between the limits Dec. 24° 0'–32° 0' are completed. The catalogue contains 12,400 stars. Every star has been observed four times, and all but 384 five times. The probable error of a single observation, calculated by taking the first star in each 10 minutes, is $\pm 8''.040$ in R.A. and $\pm 0''.43$ in declination. The probable error of the right ascensions will be slightly diminished by the application of magnitude equation. The reductions for last year's observations are nearly completed to give mean place for 1910.0. The observations for the years 1908–1913 are entered on catalogue sheets. Precessions and secular variations have been computed. Comparisons are in progress with Lalande's and Bessel's observations and with the catalogues of the A.G.C. for the determination of proper motions.

It is proposed to observe during the next five years the stars in the list prepared by Dr. Backlund and Mr. Hough. This list consists of fundamental stars equally spaced over the celestial sphere. A working catalogue has been prepared containing all the stars in the list which transit at altitudes greater than 10°—the number of entries, including the sub-polar stars, being about 3000. A new micrometer with a travelling wire has been made for the transit-circle by Messrs. Troughton & Simms, and is now being fitted.

Altazimuth.—2578 meridian transits have been observed. The Moon has been observed 64 times in the meridian and 34 times in other azimuths. The mean error of Delaunay's tables in R.A. is found to be $-0^s.21$ from the meridian and $-0^s.20$ from the extra-meridian observations. A large number of faint stars contained in Küstner's Catalogue which fall between Dec. 24° 0' and 32° 0' have been observed to assist in the determination of the magnitude-equation of the observers with the transit-circle.

From 1915·0 observations have been commenced of the stars in the "Liste des étoiles intermédiaires boréales" (Paris, 1912) which fall between the limits $0^{\circ} 0'$ and $+24^{\circ} 0'$ Dec.

Cookson Floating Zenith-Telescope.—220 plates, each exposed on a group of 4 or 5 Talcott pairs, have been taken, and also 8 plates for the determination of scale. The total number of plates taken to date with the instrument is 570 (including 23 for scale, adjustment, etc.), of which 31 have been rejected. Measurement has been completed to the beginning of August 1914.

Occultations, etc.—24 disappearances and 5 reappearances of stars occulted by the Moon were observed by one or more observers. The times of contact of the eclipse of the Sun on August 21 were observed. The transit of Mercury on November 7 was observed under exceptionally good atmospheric conditions. The results obtained from the observations of occultations, the eclipse, and the transit of Mercury have been communicated to the Society.

28-inch Refractor.—635 double stars have been measured, each star on the average being observed on two nights. They comprise—

III double stars with separation $< 0''.5$				
134	"	"	"	0.5 to $1''.0$
154	"	"	"	1.0 to 2.0
236	"	"	"	> 2.0

Among the most interesting stars observed are Sirius, Procyon, κ Pegasi, δ Equulei, γ Ophiuchi, ϵ Hydræ (Schiaparelli), β Delphini, and Aitken 570. All these stars were observed on a fair number of nights. Measures were made of the diameter of Mercury in different position angles during its transit on November 7. An account of these is given by M. Jonckheere, *M.N.*, lxxv. 31.

Astrographic Equatorial.—With this instrument 239 plates have been exposed on 99 nights. 7 plates were taken to complete the determinations of photographic magnitudes of the stars in Vol. III. of the Astrographic Catalogue. In February the taking of chart plates of the zones $+25^{\circ}$ to $+31^{\circ}$ was resumed. Some experimental photographs were taken with a wire grating which gave a difference of 3 magnitudes between the central and first diffracted images. These were in many respects satisfactory, but on account of the desirability of being able to tell at a glance stars from specks on paper reproductions from the plates, it was decided to give two exposures of $30''$ each without a grating, rather than one of $60''$ with the grating, and to sacrifice the information which would have been thus obtained about the magnitudes. 120 satisfactory photographs have been taken on Wellington "Xtreme" plates and 18 on Ilford "Monarch" plates. 40 have had to be rejected owing to interference by cloud, 25 owing to faults made by the observer in guiding or setting, and a few owing to im-

perfections in the plates. A portion of each plate has been counted, and compared with the corresponding area on the catalogue plates taken at Oxford.

The third volume of the Astrographic Catalogue giving the right ascensions, declinations, and magnitudes of 16,780 stars has been completed and published. Comparisons have been made with the catalogues of Lalande, Argelander, those of the Astronomische Gesellschaft, and some others for the determination of proper motions; in some cases measures have been made on later plates for verification. Zones 75° to 80° are completed, 70° to 74° more than half finished, and considerable progress made with zones 65° to 69° .

Thompson Equatorial.—With the 26-inch refractor 290 plates have been exposed for parallax determinations, and put away without being developed to await a second exposure; 245 plates have been re-exposed at the end of the half-cycle. 110 plates have been measured once and 22 in duplicate. The parallaxes of 7 stars, of which the results were published in June, were obtained with probable errors of $\pm 0''.01$. Further measurement and reduction was put aside for a time owing to work in connection with the Solar Eclipse Expedition and to the desirability of completing the photometry work with the 6-inch Astrographic Triplet.

Ninety-three plates have been taken to determine photographic magnitudes in Kapteyn's "Selected Areas." These consist of four exposures of 6^m each in the order Pole-Field-Field-Pole. Of these plates, 67 were considered suitable for measurement—the failures being in most cases due to change in atmospheric conditions during the time of the exposures. 34 similar plates were attempted, of which 24 were successful, of the central areas of the Franklin-Adams charts. 19 long exposures of 60^m with a grating, giving a difference of $2^m.7$, were attempted for the standardisation of the fainter stars, of which 8 were successful. 32 plates have been measured and reduced, 23 of the "Selected Areas" and 9 of the short exposures for the Franklin-Adams chart areas. Provisional magnitudes of the stars on 36 areas have been communicated to Professor Kapteyn. A few plates have also been taken with the gratings of stars Nos. 6, 11, 12, and 13 of the Harvard North Polar Sequence.

Sixteen photographs were taken for the position of Jupiter, in connection with the observations of the faint satellites which are being made at Helwân.

With the 30-inch reflector 6 photographs with exposures 20^m to 60^m were taken of Delavan's Comet. Three photographs of the comet were also taken with a 4-inch portrait lens.

6-inch Astrographic Triplet.—No photographs have been taken during the year, but the measurement of those taken in previous years has been completed. As a result the photographic magnitudes of 5500 stars between the limits of declination $65^{\circ} 0'$ and $75^{\circ} 0'$ have been determined, and will be published shortly.

Franklin-Adams Charts.—The counts of these plates have been

discussed in a paper by Messrs. Chapman and Melotte, who have determined the number of stars of each magnitude down to $17^m.0$ on the Harvard scale in different parts of the sky.

During the year 110 plates have been reproduced (32 prints of each on bromide card), thus completing the work, which has been distributed by the Society.

At the request of Mr. Innes, transparencies of the plates taken at Johannesburg are being made—the Union Observatory paying the cost of the materials. So far 66 plates have been copied, and the whole will be completed very shortly.

Photoheliograph.—Some further alterations have been made in the dome of the old altazimuth, where the Dallmeyer photoheliograph is now housed. A developing room has also been made in the same building. Photographs of the Sun were obtained with this instrument on 238 days during 1914. In the year ending October 31 photographs have been obtained on 305 days at the Cape. Twelve photographs have been received from Kodaikanal and 10 from Dehra Dûn. Pictures of the Sun are in this way obtained for each day of the year to October 31.

The Greenwich photographs are measured to the end of the year, and those from the Cape to the end of September.

The solar activity showed a great increase soon after the beginning of 1914. In January and February the spotted area was only 11 millionths of the Sun's visible disc, but increased in April and May to 280 millionths. In later months the spotted area has been much greater than in recent years, though less than it was in April and May.

Total Eclipse of the Sun.—An expedition was sent from the Royal Observatory to Minsk in Russia. The observers, Mr. Jones and Mr. Davidson, accompanied by Mr. Hepburn as a volunteer assistant, were fortunate in the weather conditions, and carried out the programme of observations very successfully. A preliminary report of the expedition has been communicated to the Society, and is published in the *Monthly Notices* for January 1915.

Personal.—The Observatory has lost the services of Mr. S. Chapman, who returned to Trinity College, Cambridge, on October 1, after a short but very valuable term as Chief Assistant. He was succeeded on October 8 by Mr. J. Jackson, Scholar of Trinity College, Cambridge.

Owing to the war the staff of the Observatory is at present somewhat depleted, Mr. Burkett, Junior Assistant, and ten of the senior computers having volunteered for active service.

Mr. Jonckheere, Director of the Lille Observatory, has been at the Observatory since October 16, observing with the 28-inch refractor, where he has, among other work, discovered 45 new pairs; he is also engaged on a catalogue of double stars discovered since 1905, a work which he commenced several years ago at Lille.

The Astronomer Royal was granted leave of absence in order that he might attend the meetings of the British Association in Australia, and was absent from the Observatory from June 22 to

Oct. 4. On the outward journey, a very interesting and enjoyable visit was made to the Cape Observatory, in company with several other English astronomers. In Australia he had the pleasure of visiting the observatories and meeting the astronomers at Perth, Adelaide, Melbourne, Sydney, and Windsor. In consequence of the war his intention of visiting New Zealand was abandoned.

Royal Observatory, Cape of Good Hope.
(*Director, Mr. S. S. Hough, H.M. Astronomer.*)

The death of Sir David Gill, whose life's work was so intimately associated with the Cape Observatory, has been the occasion of great grief to every member of the staff. His interest in the work of the establishment and in the welfare of all connected therewith was maintained to the last, and all alike feel the loss as that of an intimate personal friend.

Transit-Circles.—The new transit-circle has been employed in continuation of the programme of previous years for the observation of stars contained in the Backlund-Hough list, together with such of Boss's fundamental stars as were not included in the previous working list.

The following observations have been obtained during the year:—

Observations of Right Ascension:—

Number of meridian transits	7250
Determinations of collimation by collimators	97
" " " by reflexion	
and reversal	25
Determination of level	727
" " azimuth	132
Observations of Meridian Marks	1346

Observations of Zenith Distances:—

Determinations of Z.D.	6848
" " runs	346
" " nadir	715
" " flexure	61

Included in the number of observations are:—

Observations of the Sun on 136 days	
" " Mercury " 47 "	
" " Venus " 59 "	

The non-reversible transit circle has been used by Mr. J. Voûte, an assistant from Leyden, on a programme for the determination of stellar parallax. The working list consists of 115 parallax stars with an average of 5 comparison stars to each.

In the course of the year the following observations have been secured :—

Evening observations	.	.	6492	transits
Morning observations	.	.	6284	„
Azimuth stars	.	.	48	
Time stars	.	.	41	
Collimation errors	.	.	49	

Heliumeter.—The instrument has been employed for the observation of the major planets at the time of opposition, and the following observations secured :—

Opposition of Mars	.	28	obs. in distance	} on 6 nights.
		10	„ „ position-angle	
„ „ Jupiter	.	36	„ „ distance on 6 nights.	
„ „ Saturn	.	36	„ „ „	6 „
„ „ Uranus	.	48	„ „ „	6 „
„ „ Neptune	.	44	„ „ „	6 „

A revision of the triangulation of the area surrounding the South Pole has been commenced during the year, and observations for this purpose have been secured on 53 nights. The observations comprise 738 measures of distance, including 128 measures of a standard pair for the control of the instrumental scale value.

Victoria Telescope and Astrophysical Laboratory.—The telescope was used on 185 nights during the year. During May and June and again during September and October the spectrograph was dismantled for the purpose of obtaining direct photographs of Jupiter's Galilean satellites near the epoch of quadrature of the planet. Forty-one photographs were obtained, each with 6 images of Jupiter and its four bright moons, and 2 exposures to a selected star region.

The principal work of photographing stellar spectra for radial velocity determinations was carried on during the remainder of the year, and 203 plates were secured on 147 nights.

Thirty-two daylight spectra and 18 focus plates were also obtained.

An unexpected bright comet was discovered by Dr. Lunt on September 18. Its cometary nature was not definitely ascertained until two days later. The comet was photographed with the 24-inch telescope on 2 nights and measures of its position were made with the Repsold micrometer on the 18-inch telescope on 17 nights.

The comet was independently discovered about the same time in New Zealand, Tasmania, and South America. It was subsequently visible in Europe.

In the laboratory 273 plates have been measured for radial velocity of stars, including 61 daylight spectra for standardisation of standard stellar spectra.

In addition, 43 plates of spectra of meteoric irons, etc., were photographed.

The Astrographic Telescope.—The following photographs have been secured with this instrument during the year:—

Description of Plate.	No. of Plates.	No. of Exposures.	Duration of Exposure.
Magnitude plates	17	68	20 ^m , 6 ^m ; 20 ^m , 6 ^m
South Polar region, for magnitude	3	96	various
Comparison plates	2	4	6 ^m , 20 ^s
Comet 1914 <i>e</i>	32	34	various
With screen-attachment magnitude plates	13	193	„
Parallax plates, with exposures at 2 epochs	3	6	...
Double-star plates	36	...	...

Photoheliograph.—Daily photographs of the Sun, to supplement the Greenwich series, have been secured on 311 days. In all 642 negatives were taken, of which 6 have been rejected and the remainder forwarded to Greenwich for inclusion with the Greenwich series.

Occultations.—Twenty-three separate phenomena of occultations of stars by the Moon have been observed during the year, viz.:—

Disappearances at dark limb	12
Reappearances „ „ „	11

Reductions of Meridian Observations.—The reductions of meridian observations to apparent place have been completed to 1914 October 9 in Right Ascension, and to 1914 December 14 in Declination. The reductions to apparent place have been computed for all observations to 1914 October 27, and mean places have been formed for all observations to the end of 1912.

Details of the meridian observations made with the two transit-circles during the years 1905–8 have been passed through the press, and those for the years 1909–11 have been completed for press.

A catalogue based on the observations of the years 1905–11 has been passed through the press during the year, with the exception of the Introduction, which is now in the printer's hands.

The observations of 1911, which were largely confined to a selected series of circumpolar stars, have been subjected to a special discussion, including a determination of the aberration constant. This has been issued during the year as part iii. of vol. xi. of the *Cape Annals*.

“Carte du Ciel” Reductions.—The work of the year has consisted principally of revision work resulting from comparisons with the C.P.D. and comparisons of overlapping areas. 732 pairs of overlapping quadrants have been compared during the year, and the discordances examined and revised for 192 complete plates.

The outcome of experiments made with a view to the standardisation of the magnitudes of the stars has been communicated to

the R.A.S. in two papers by Dr. J. Halm (*M.N.*, vol. lxxiv. p. 600, and vol. lxxv. p. 150).

Vol. i. of the *Cape Astrographic Zones*, containing the rectangular co-ordinates and measures of diameters of stars contained on the astrographic plates in zone -41° , has been issued; vol. ii., containing similar results for zone -42° , has been passed through the press; while the manuscript for vol. iii. has been sent to the printers. Proof-sheets of the latter volume have been passed for the first twelve hours of R.A.

Vol. xii. part i. of the *Cape Annals*, containing a discussion by Dr. W. de Sitter of a series of heliometer observations of Jupiter's satellites made in the year 1891, has been sent to press; while vol. xii. part v., containing the derivations of the final inclinations and nodes of the orbital planes of Jupiter's satellites from the *Cape Observations of 1891, 1901-4*, has been issued.

Time-Signal Service.—Arrangements have been made with the Post Office authorities for the daily transmission of a time signal from the wireless station at Slangkop for the use of shipping in South African waters. The signals are actuated automatically from a clock in the Observatory, which is regulated daily. The service has been in operation since September 1. In other respects the usual time-signal service has been continued.

Miscellaneous.—The meteorological observations and seismograph records have been maintained as in previous years.

Royal Observatory, Edinburgh.

(*Director, Professor R. A. Sampson, Astronomer Royal
for Scotland.*)

Transit Circle and Clocks.—The primary objects in view have been the study of the changes in the Transit Circle and the conditions for precise determination of time. The former study has been pursued upon the lines indicated in the last report, namely, by readings made three or four times each day of the instrumental errors, including the relative azimuth of the transit circle and the collimators. A discussion of a complete year's observations has shown a clear connection of the changes of azimuth and level with temperature, the effects being divided into a rapid superficial change, superposed to a slower basic change, the latter being of twice the amplitude of the former. An interesting question has arisen on the relative reliability and differences of instrumental azimuths taken from the collimators and stellar azimuths from polars. A discussion of the observations up to September 30 has been published in *Monthly Notices*, lxxv. p. 69 (1914 December). The observations are continued. Control of the temperature of the clock-chamber has been maintained fairly satisfactorily, but with some difficulty, owing to fouling of the contact thermometers employed. Different devices were tried, in order to escape the use of mercury and offer a surface that could be cleaned readily,

but in the end a return was made to a newly-made mercury thermometer. At the present time this is working without fault. A number of naval chronometers and watches are now rated at the Observatory and supplied on demand for the use of His Majesty's ships.

Wireless Time-Signals.—In connection with time determination a great deal of attention has been given to the wireless time-signals sent out from Paris and Norddeich. In particular the rhythmic signals have been taken at 11.30 p.m. each night with few omissions. After some correspondence with M. Baillaud, it was arranged to telegraph the resulting clock comparison of each night to Paris on the following forenoon. This was done from May 28 to August 3, when the aerial was dismantled and removed by the Post Office upon the outbreak of the war. The apparatus has, however, now been restored, subject to certain conditions, and the programme will be resumed in a short time when a few changes have been made necessitated by the restrictions imposed.

Solar Spectroscopy.—During the spring a fine concave grating by Rowland, the property of the University, was lent to the Observatory, and replaces, for the time being, our plane grating; it has been mounted in a manner generally similar to that used by Professor Fowler, namely, with the camera fixed alongside the slit. The radius is 21 feet. After many experiments it was decided to take a series of photographs of opposite limbs in the region of the spectrum— $\lambda 6300$ —employed in our former investigation, relying for comparison upon atmospheric lines. Some photographs were taken with the fifth order, and though the results were good, the length of exposure was too severe a handicap, and at present the third order is employed. The plates obtained in the past summer have been measured in one position of the measuring machine. It is proposed to examine them carefully to see what light they throw upon the origin of discordances between measures found by different observers.

Fifteen-inch Equatorial.—Double-star observations have been continued as heretofore. Some exposures have been made with the prismatic camera upon stars and upon comet Delavan.

Astrographic Catalogue.—During the year 44 plates in zone -38° have been measured out of the zones observed at Perth, Western Australia. With the exception of 7 plates, the zones -40° , -39° , -38° are now completely measured.

The computation of standard co-ordinates for zone -39° has been completed, and the plate constants for the same zone are now in process of calculation.

Seismograph.—Continuous observations have been kept up with the Milne seismograph, and the results communicated to Shide.

Electrograph.—Observations have also been maintained continuously with the water-dropping electrograph.

Meteorology.—The usual readings have been made and are communicated regularly to the Meteorological Offices at Edinburgh and London. During the year the Robinson cup anemometer has

been replaced by a Dines pressure-tube anemometer with Munro-Rooker direction recorder. This was completed in August. The records obtained have been very satisfactory.

Library.—During the year the Royal Society of Edinburgh organised a tercentenary celebration of the invention of logarithms, and upwards of a hundred volumes were lent for exhibition from the library of the Royal Observatory in illustration of the history of the subject. A bibliographical description of the exhibit was also prepared and is in course of publication.

Staff.—During the year Mr. E. A. Baker, B.Sc., joined the staff in succession to Mr. H. Jameson.

Cambridge Observatory. (Director, Professor A. S. Eddington.)

Owing to vacancies in the staff, and the extra work incidental to changes therein, it has not been possible to make much progress with observational work during the past year.

At the beginning of the year the Directorship of the Observatory was vacant, Professor Newall filling the office of Acting Director. The present Director was appointed on March 14; but the return to a normal state of working in the Observatory was further unavoidably delayed by his absence for four months for the Meeting of the British Association in Australia.

The post of Second Assistant, which was also vacant, has been filled by the appointment of Mr. F. Entwistle, formerly Computer at the Royal Observatory, Greenwich, who joined the staff on December 1.

The Meridian Circle has been used for observation of zodiacal stars on 8 nights, the number of observations being 243. The reductions to Apparent Place are calculated to 1909 December 31 in Right Ascension, and to 1912 April 25 in North Polar Distance, and the reductions to Mean Place to 1909 May 5. A pair of gauze screens have been procured for the purpose of determining the magnitude equation of the observer (Mr. Hartley).

The Ledger of Zone Observations (*Astronomische Gesellschaft Catalogue*) has now been printed as far as R.A. 23^h 12^m.

In the last month of the year attention has been mainly given to setting the Sheepshanks equatorial in working order for a renewal of observations for stellar parallax; the work has been delayed by trouble with the driving-clock.

The usual demonstrations in practical astronomy have been given at the Observatory by the Chief Assistant. Instruction in field astronomy, etc., has been also given to students of geography by Mr. C. S. Wright, University Lecturer in Cartography and Surveying. The Northumberland equatorial (and occasionally the Sheepshanks equatorial also) is used on clear Saturday nights in the winter months to show celestial objects to members of the University and their friends. Mr. Rolston has given very welcome volunteer assistance to Mr. Hartley in this work.

Solar Physics Observatory, Cambridge University.
(Director, Professor H. F. Newall.)

Spectroheliograph.—Photographs of the Sun's disc in K_{2-3} light have been obtained on 144 days, and photographs of the prominences at the limb on 104 days. The solar activity has slowly but definitely increased during the year.

For the period 1913 October 1–1914 September 30, the Director of the Kodaikanal Observatory has sent 326 spectroheliograms, showing the solar disc in calcium (K_{2-3}) light. Of the 39 days missed in the Kodaikanal records during this period, the Cambridge record has photographs for 14 days.

Photoheliograms.—Daily photographs taken with the Dallmeyer photoheliograph at Dehra Dûn have been received, and the negatives are stored at the Science Museum, South Kensington. Positive prints have also been received from Dehra Dûn. Spectroheliograms have been enlarged to the same size for comparison.

Study of Sun-spot Records.—Considerable progress has been made in the study of the areas and life-history of Sun-spots from the Greenwich records 1889–1901, and work has been begun in the examination of the heliocentric distribution of Sun-spots and is progressing for the two cycles 1889–1901 and 1901–1912.

Solar Eclipse 1914 August 20–21.—Preparations for observations planned to be made near Theodosia, Crimea, occupied considerable time in the spring and early summer, especially in the mounting and adjustment of the 6-inch Rowland grating for observations of the spectra of the Sun's limb and of the corona. Unfortunately clouds completely obscured the view of the eclipsed Sun and no results could be obtained.

McClellan Solar Instruments.—In making tests of the new 12-inch object-glass, signs of zonal errors were traced to the two 16-inch mirrors of the cœlostæt. The mirrors have been refigured by Messrs. T. Cooke & Sons, and were remounted in position in October.

Investigations of Stellar Spectra.—The Cambridge spectrograms of Nova Geminorum No. 2 have been completely measured and discussed by Mr. F. J. M. Stratton. Publication of the results obtained was postponed, as fresh material filling up most of the gaps in the Cambridge series was kindly offered by Dr. Schlesinger, Director of the Allegheny Observatory. The few dates left unrepresented in the Cambridge and Allegheny series were filled by spectrograms kindly sent for study by Dr. Küstner, Director of the Bonn Observatory. The measures and most of the reductions of this fresh material have been made, but the eclipse work and the war have combined to cause a further postponement in the publication of results.

Considerable progress has been made in the work of assigning chemical origins of lines in stellar spectra, in preparation for an atlas of typical stellar spectra.

A paper by Mr. Baxandall on the enhanced lines of manganese in the spectrum of α Andromedæ was communicated to the Society (*M.N.*, vol. lxxiv. 250). This star and μ Leporis (mag. 3.5) seem to be the only recorded instances of this peculiarity.

The green region of the spectra of several of the brighter stars has been studied by Mr. Baxandall in photographs obtained by Professor Newall in 1905 with the four-prism spectrograph attached to the 25-inch telescope. The results of measurements and comparison of various typical spectra are being prepared for publication.

Huggins Instruments.—The new spectrograph has been adjusted and is nearly ready for regular work. Various stellar spectrograms have been obtained during the process of adjustment.

The 3-foot Reflector.—The erection of the heavy parts of the 3-foot reflector in the new dome built for it was successfully accomplished in March. The alterations made for improving the counterpoising of the instrument are found to be quite satisfactory. A plan for the staging required for manipulating the instrument in all positions was worked out, but the pressure of preparations for the eclipse made it necessary to defer the completion of the work.

Work in the Laboratory.—The detention at Odessa of the instruments taken to the Crimea for eclipse observations has impeded progress in experimental work in the laboratory. A temporary spectrograph is being constructed in Littrow form, so that work can be carried on with the 6-inch plane grating by Anderson and the 6-inch photovisual lens of focal length 20 feet.

Mr. Rossi has published the results of his work on the widening of the lines in the spark spectrum of Hydrogen (*Astroph. Jour.*, xl. 232); and in studying the displacements of lines in spectra of the Sun's limb, he has measured and discussed a considerable number of photographs of the region of the spectrum about wavelength 6300 taken by Professor Newall in 1908. The photographs give material for comparison of the displacements (at the east, west, north, and south limbs, and at the centre of the disc) of solar lines relative to oxygen lines of telluric origin.

Investigations in Atmospheric Electricity.—Mr. C. T. R. Wilson has developed apparatus for studying quantitatively some of the more important phenomena of atmospheric electricity. In the method worked out, one and the same apparatus is sufficient to measure (i.) the charge on the surface of the ground, or in other words the vertical electric field or potential gradient at the surface; and (ii.) its variations, including the almost instantaneous changes of field which result from lightning discharges; and (iii.) the current from the atmosphere into the ground, whether due to conduction by the movement of ions under the action of the field or to convection by falling raindrops. Mr. Wilson has succeeded in measuring the instantaneous changes of field resulting from distant lightning flashes, and in gaining information bearing on the quantity of electricity discharged in a flash.

The study of the tracks of ionising particles in gases by the

condensation method has also been continued by Mr. Wilson with improved apparatus. Stereoscopic photographs of the tracks have been obtained and the interpretation of the records has thereby been greatly facilitated.

Library and Lectures.—Considerable progress has been made in the arrangement, binding, and cataloguing of the books in the Library, in the charge of Mr. Rolston.

Lectures have been given by Professor Newall on solar research, and by Mr. Stratton on stellar physics.

Dunsink Observatory.

(*Director, Professor H. C. Plummer, Royal Astronomer of Ireland.*)

The Pistor and Martins meridian circle has been used for the determination of time only, and the time service to Dublin has been continued as in former years. Wireless receiving apparatus for time-signals was installed in the summer, and was giving satisfactory results when events required its discontinuance.

The South equatorial has been used to show objects of interest to visitors on the first Saturday of each of the winter months. Occultations of the Pleiades have been observed twice.

With the Roberts reflector 279 plates were taken during the year in connection with the variable star work. Papers on XZ Cygni, and on the variables in the region of χ Persei have been communicated to the Society. A few plates of Delavan's comet were taken with the reflector and with the 6-inch doublet attached.

The staff remains unchanged. A course of lectures on the theory of practical calculation was given by the Director in the Hilary term.

Durham University Observatory.

(*Director, Col. E. H. Hills, C.M.G., D.Sc., F.R.S.*
Observer, F. C. H. Carpenter, Esq., B.Sc.)

The first half of the year was devoted to work with the almucantar, combining visual observations with readings of the level alluded to in the last report. About 350 stars have been observed, and it was hoped that sufficient material had been collected to give some indication of the cause of the changes in zenith often found in the course of a few hours. It has, however, not yet been possible to discuss the results.

Upon the outbreak of war the observer (Mr. Carpenter) left the Observatory to take up service in H.M. Forces, and has not been replaced.

Astronomical work has therefore been dropped *pro tem.*, and only the routine meteorological readings taken.

The suspended zenith telescope was nearly completed by Messrs. Cooke in July, and in ordinary course would have been mounted in September or October. This has had perforce to be laid aside, it is hoped for no very prolonged period.

The Liverpool Observatory, Bidston.
(*Director, Mr. W. E. Plummer.*)

Some interruption of the work has necessarily been occasioned by the outbreak of war. On August 3, the Post Office authorities dismantled the wireless equipment, and on the following day the Government took over the Observatory as a telephone station for linking up some of the scattered units connected with the South Mersey Defence. Eighteen men of various ranks were drafted into the Observatory, and for some time the ordinary work could be carried on only with difficulty. The numbers of the military were gradually reduced, till, at the end of October, improved telephonic arrangements were completed, the forces withdrawn, and normal conditions returned.

The removal of the radiotelegraphic apparatus and the delay in issuing the meteorological reports have seriously hampered the enquiry, mentioned in the last report, having for its object the correction of tidal predictions by incorporating the meteorological conditions, existing or anticipated. Though some of the larger discrepancies seem utterly lawless and inexplicable, very considerable progress had been made in the beginning of the year, and the prospects were hopeful. In other respects, the routine work of the Observatory, consisting principally of the observations of comets and variable stars, of meteorological observations, the testing of scientific apparatus, and the distribution of time-signals has been conducted without interruption. The dislocation of trade by the war has not materially affected the number of chronometers and other instruments deposited for test.

A new seismometer has been mounted by Mr. J. J. Shaw of West Bromwich, of his own construction. The principle of registration by displacement, adopted by Milne, has been preserved, but it differs from the Milne instruments by being so heavily damped as to be practically aperiodic. The damping is effected by attaching a copper vane to the horizontal pendulum, allowing it to move in a strong magnetic field. Increased sensitiveness is provided by reflecting a beam of light from a small mirror, engaging with the end of the pendulum. Practically a tilt of one-tenth of a second causes a displacement of the point of light through seven millimetres. Provision is also made for very accurate measurement of the tilt. Experiments for test were carried on in November and December, and regular observations began this year.

Radcliffe Observatory, Oxford.
(*Director, Dr. Rambaut, Radcliffe Observer.*)

During the year 1914 the scheme of work with the 24-inch photographic refractor, which consists in photographing Professor Kapteyn's "Selected Areas" for the purpose of determining the proper motion of the stars down to the 14th magnitude, has been carried on as in recent years at this observatory.

The weather at Oxford has been on the whole rather less unfavourable than in 1912 and 1913, and somewhat better progress has been made. In connection with this scheme 72 plates, each requiring two exposures of 30 minutes, have been obtained. Of these, 10 are more or less incomplete, leaving 62 plates which are considered satisfactory for the purpose in hand. During the year 24 undeveloped negatives have been packed up in air-tight boxes, and 12 more are now ready for storage.

Other objects photographed with this instrument are the variable star RW Draconis (2), Polar region (10), various for focus and to test the adjustment of the objective (9), and the Moon (6). During the Transit of Mercury on November 6-7, also, 24 photographs of the Sun were taken showing the planet in transit. One of these plates was spoiled by clouds, but the remaining 23 have been fully measured and reduced. The results have been communicated to the Society and published in the *Monthly Notices*, lxxv. 3. They give as the corrections to the R.A. and Declination of the planet's centre, relative to that of the Sun, $\pm 0^s.109 \pm 0^s.012$ in R.A. and $+ 0''.93 \pm 0''.12$ in Dec.

Unfortunately a few of the proper-motion photographs have been taken on a batch of plates some of which, on being developed in the ordinary way, proved to be inferior in sensitiveness to the makers' usual standard, and to be somewhat defective in other respects. It may, therefore, be advisable to take these proper-motion fields again with plates which come up to the normal standard of excellence.

Of the 252 "Selected Areas" contained in Professor Kapteyn's Plan, 136, which lie between $+90^\circ$ and -1° in declination, have been undertaken for proper motion by the Radcliffe Observatory. Towards the end of July (1914) 43 of these areas still remained to be photographed, and as most of them are contained in the earlier hours of right ascension, they would in the ordinary course come into position for observing at a time of year when the weather is usually most unfavourable at Oxford. In order to overtake these arrears accordingly early morning watches were arranged during the later months of the year (September to December). Some progress was made in this way, but during the last three months the weather was particularly bad and the number of plates secured fell considerably short of what had been hoped for. At the end of the year the working list still contained 33 fields not

yet completed, of which 31 lie between $1^h 50^m$ and $11^h 59^m$ in R.A., and 8 of them in the fourth hour of R.A.

The 24-inch objective was taken apart and the lenses cleaned towards the end of March, after which they were carefully readjusted and the objective as a whole "squared on" by April 1.

As was stated in the report for last year, owing to an accident it became necessary to readjust the polar axis of this instrument, and this was effected by observations made in November 1913. In order to test the stability of this adjustment the observations were repeated in February 1914, with very satisfactory results. As finally adjusted in November, the residual errors in altitude and azimuth were $-3''.7$ and $-4''.9$ respectively. After an interval of two months and a half they were found to be $-1''.1$ and $-4''.5$, showing a degree of permanence in the adjustment which was hardly to be expected.

The 10-inch Barclay equatorial has been used for miscellaneous observations, including the Partial Eclipse of the Sun on August 20-21. During the Transit of Mercury it was employed in measuring the form of the planet's disc, 79 micrometer measures of six diameters having been made. The Marlborough $3\frac{1}{4}$ -inch telescope was employed for observing the times of contact during the Partial Eclipse of the Sun and the Transit of Mercury. The results of these observations with the Barclay and Marlborough instruments have been communicated to the Society and published in the *Monthly Notices*, lxxv. 1 and 3. The Barclay equatorial has also been employed, as in former years, for observations of a selected list of variable stars. This list includes RW and ST Draconis; VV Aurigæ; 4, 1913 Tauri; and 5, 1913 Arietis. Of these, 119 observations (464 separate comparisons) on 28 nights have been secured. A paper entitled "Note on the Variable Star VV (17, 1912) Aurigæ," by Mr. Barrett, was published in the *Monthly Notices*, lxxiv. 6, giving the results of his observations of this star up to date.

The measurement and reduction of the parallax plates taken in recent years with the 24-inch refractor have, with one or two interruptions, been carried on steadily throughout the year. Six Kapteyn plates have been studied within that period, and 35,653 micrometer measures have been effected for parallax. In addition to these, 6335 measures have been made on 24 photographs in connection with the Transit of Mercury, and 1889 measures on 2 photographs of the region surrounding RW Draconis, amounting in all to 43,877 micrometer measures of photographs made with the measuring machine during the year.

The reduction of the measures also has been pushed forward vigorously. The measures of the 6 plates referred to above have been completely reduced, and 3 plates measured during the previous year have also been worked off.

At the end of 1913 the card-catalogue contained 4017 separate determinations of the parallaxes of 1875 stars. During the year recently ended 1304 separate values were deduced, and 587 stars

added to the catalogue, making a total of 5321 separate determinations of parallax for 2462 stars now awaiting final discussion and publication.

Early in the year vol. li. part iii. of the *Radclyffe Observations*, containing the results of meteorological observations during the year 1913, was printed, and a limited number of copies distributed. Part iv. of the same volume, covering the year 1914, is now in the printers' hands. The volume when complete will include the results for the five years 1911-1915.

University Observatory, Oxford.
(*Director, Professor H. H. Turner.*)

A number of other problems and enterprises have diverted attention from the reduction of the photographic observation of reference stars, so that no further progress has been made during the year.

The reductions for the Vatican plates, undertaken at this Observatory, have gone on steadily. Zone $+64^{\circ}$ is now fully printed, and the last sheets of the introduction are being passed for press. Zones $+63^{\circ}$, $+62^{\circ}$, and $+61^{\circ}$ are all reduced, with the exception of one plate (superseded) in $+61^{\circ}$; and the standard co-ordinates of $+60^{\circ}$ have been computed.

The harmonic analysis investigations had led to a method of testing for discontinuity which, at the time of the last Report, had been applied to the records of Sun-spots, and had suggested discontinuities of period due to the Leonid swarm of meteors. It was natural to apply the test for discontinuity to the rainfall observations which have been under analysis for many years. The periodicities of 5 months and 19 months, which had been suggested by the periodogram analysis, were tested for the Greenwich, Klagenfurt, and Padua series, with the result that a series of dates were suggested at which changes took place in all the series. These dates come at approximate intervals of $6\frac{1}{2}$ years, but the deviations from a uniform interval observe a cycle of 41 years. When the 6-monthly period of Padua rainfall was then analysed, breaks were found, within reasonable limits, at the dates adopted independently from the other series: and the cycle of 41 years was manifested in the behaviour of the 6-monthly period between the critical dates. The critical dates themselves show a connection with the epochs when the movement of the Earth's axis is a minimum, following these minima by about a year. This investigation, which involves considerable labour, and may be regarded as the principal work of the year, is being extended to other series of data.

The Director has continued the superintendence of the seismological work at Shide. The performance of the Milne pendulum

as compared with others has been discussed, and it was shown that while the accuracy of the Milne pendulum—a simple instrument devised for pioneer work—leaves something to be desired, its wide distribution makes its records of essential value. Experiments to improve its accuracy, without great expense, have proved very successful. The Shide Circulars have been converted into Monthly Bulletins, which show the comparison of observed times at the various stations with existing tables; and the correction of these tables is in progress. The Shide wireless time-signal apparatus was dismantled on the outbreak of war, and for some months there was a difficulty in getting accurate time. The loan of a transit by this Society has put an end to the trouble.

Volume IV. of the *Transactions of the International Union for Solar Research* was passed through the press in the early part of the year.

With the able assistance of Miss M. A. Blagg, Baxendell's Observations of eight Variable Stars have been reduced and printed (*Mon. Not.*, lxxiv. p. 451 and p. 568). Other stars are nearly ready for press.

Counts of stars of different photographic magnitudes have been made in one complete zone of the published results for the Cape Observatory (*Mon. Not.*, lxxv. p. 57), the Perth (W.A.) Observatory (in the press), and the Vatican Observatory (in MS.). The results, taken with others already published, indicate that there are sensible variations in the ratio of faint stars to bright, but that these variations are not related to the Galaxy. Other results will be published before any attempt is made to map out the regions richer in faint stars definitely.

The Director took part in the meeting of the British Association in Australia, which was fully carried through in spite of the outbreak of war. The astronomers present were glad to avail themselves of several invitations to visit Australian observatories, including that of Mr. Tebbutt. On the way out the Director visited the Colombo Observatory; and, on the way home, the observatories of Kodaikānal, Madras, and Hyderabad, and the meteorological station at Simla.

Mr. R. S. Capon, the second assistant, availed himself of a very kind offer by Professor Hale to spend a year at Mount Wilson. That, at any rate, was his intention when he started in July last, and he has had six months' valuable experience; but on the outbreak of war he volunteered for service, and, though there have been delays in finding acceptance, he is now on his way home to enter on military duties.

Mr. A. E. Young continued to work as a volunteer at the Observatory for the first half of the year: but since the outbreak of war has found other occupations.

The receiving apparatus for wireless signals at this Observatory was dismantled at the outbreak of war.

The Coats Observatory, Paisley. (Convener, Mr. John Woodrow.)

The meteorological and seismological work has been carried on without intermission during the year, but owing to the illness of the curator, the Observatory was not open to the public until the month of March. During the curator's illness, the Observatory was under the care of Mr. John Woodrow, junr., a member of the Council.

Since January the Observatory has been co-operating with the Meteorological Office, London, and it is now recognised as an Anemograph Station.

Both the solar eclipse of August 20-21 and the transit of Mercury of November 6-7 were watched at intervals through the equatorial, but weather conditions were not such as to favour the taking of photographs.

Temple Observatory, Rugby. (Director, Mr. G. M. Seabroke.)

This Observatory has been used chiefly for school purposes, being open for boys every clear evening, and the attendance has been good. Mr. Hewlett interests the smaller boys with a commentary on objects seen, and in the autumn term there is a class for instruction in the use of the transit, micrometer, etc.

Last spring a wireless receiving apparatus was installed, which proved very attractive to some older boys, one of whom constructed a receiver himself. The Eiffel Tower signals were very distinct.

*Hill Observatory, Salcombe Regis, South Devon.
(Director, Sir Norman Lockyer, K.C.B., LL.D., D.Sc., F.R.S.)*

Observations.—The weather has not been very favourable for photographic work during the past year. The two instruments mentioned in the previous report have been employed, viz. (a) the Rusthall 12-inch prismatic camera, carrying a 12-inch prism of 20° angle, and (b) the 9-inch prismatic camera with a 9-inch prism of 45° angle worked in connection with a 21-inch siderostat.

The work with the Rusthall telescope has been confined chiefly to the photography of the spectra of stars, i.e. stars fainter than the fourth magnitude, which have not been included in the Kensington classification of the 470 brighter stars. The number of new spectra which has been secured is 139, while 69 spectra of the 470 brighter stars have been rephotographed. Seven photographs of the spectrum of Mira Ceti and twelve photographs of the spectrum of Comet 1913 f (Delavan) have also been taken.

With the 9-inch prismatic camera 82 stellar spectra were obtained, in addition to numerous plates for prism testing and adjusting purposes. This instrument, however, was not in use for the whole period covered by this report, as the optical parts were sent to Messrs. T. Cooke & Sons, York, for adaptation to the new tube and camera under construction there.

Laboratory.—In the laboratory the Littrow grating spectro-scope has been readjusted to secure a more satisfactory definition over a larger range of spectrum. A few comparison spectra of arc and spark have been photographed with it.

Discussions.—All the photographs of stellar spectra taken with the Rusthall telescope have been classified according to the Kensington classification scheme. Researches dealing with the flame spectrum of iron, the distribution of variable stars in relation to the Kensington classification temperature curve, etc., are in progress.

Publications.—The first number of the Observatory's Bulletin was issued in November, and contained the first of a series of "Notes on Stellar Classification."

Library.—The library has been enriched by the addition of numerous pamphlets, publications, etc., sent to the Observatory by many observatories and individuals. It has also received a number of astronomical books.

Buildings.—The dome for the 10-inch refractor and the 9-inch prismatic camera (both instruments on one equatorial mounting) have been completed, together with an annexe containing a dark room.

Miscellaneous.—The wireless installation was dismantled by the Post Office engineers on August 3. Plane and concave mirrors up to 9.5 inches aperture, required for some contemplated inquiries, have been silvered.

Staff.—The staff has been increased by the appointment of a third assistant, Mr. N. K. Johnson, A.R.C.S., B.Sc., who commenced his duties in August.

Imperial College, South Kensington.
(Assistant Professor, A. Fowler.)

As in former years, the instruments were chiefly used for the instruction of students, but also for occasional observations of the spectra of Sun-spots and metallic prominences.

In collaboration with Col. Hills, much time was occupied in preparations for an expedition to Russia for observations of the total solar eclipse of 1914 August 21. Owing to difficulties arising from the war, however, the expedition was abandoned, and considerable inconvenience has been caused by the detention of the instruments at Riga (see *M.N.*, vol. lxxv. p. 117).

Spectroscopic observations of the partial eclipse of the Sun on August 21 were made at South Kensington (*M.N.*, vol. lxxv. p. 24). The transit of Mercury on November 7 was also observed under very favourable conditions (*M.N.*, vol. lxxv. p. 36).

Further laboratory investigations were made in connection with the origin of the lines 4686, etc., which were obtained in 1912 by passing strong discharges through helium tubes, chiefly with a view to estimating the value of the numerical evidence on which the assignment of these lines to hydrogen mainly depended. The result was to show that the enhanced lines of magnesium, calcium, strontium, and barium form series of a new type, in which the Rydberg constant has four times its usual value. It now appears that the lines in question form a series of the enhanced line type, and should be regarded as enhanced, or spark, lines of helium (Bakerian Lecture, *Phil. Trans.*, A, vol. ccxiv. p. 225, 1914).

Mr. Curtis made careful determinations of the wave-lengths of the first six members of the Balmer series of hydrogen lines, from which he arrived at the value 109,679.22 for the series constant on the international scale (*Proc. Roy. Soc.*, A, vol. xc. p. 605, 1914).

Mr. Jevons investigated the interaction of boron compounds with active nitrogen, and discovered a new spectrum of bands which is attributed to boron nitride (*Proc. Roy. Soc.*, A, vol. xci. p. 120, 1914).

An investigation of the effects of pressures up to 11 atmospheres on the spark spectrum of nickel was made by Mr. E. G. Bilham, research student. The chief purpose of the work was to obtain accurate measurements of the displacements of the lines, over the range of pressure which is of greatest interest from an astrophysical standpoint (*Phil. Trans.*, A, vol. ccxiv. p. 359, 1914).

Mr. J. S. Clark, research student, made determinations of the wave-lengths of the chief lines of nitrogen and oxygen in the region usually studied in stellar spectrograms, viz. $\lambda 3880$ to $\lambda 4700$. The spectra were produced under conditions which gave the lines with extreme sharpness, and were photographed in the third order of the 10-foot concave grating. It is hoped that the measures may be of use in connection with investigations of the radial velocities of certain classes of stars (*Astrophys. Jour.*, vol. xl. p. 332, 1914).

An extension of Goldstein's experiments on "Grundspectra" was attempted by another research student, Mr. E. Nelthorpe. In stars of early type, enhanced lines are isolated from the arc lines with which they are usually associated in laboratory spectra, and the experiments showed that Goldstein's method gives a close approximation to this condition (*Astrophys. Jour.*, January 1915).

Mr. J. B. Hubrecht worked for a short period in the laboratory and commenced an investigation on the enhanced lines of nitrogen and oxygen.

On his return from Russia Mr. Curtis enlisted in the Engineering Section of the Royal Naval Division, for service during the war.

Stonyhurst College Observatory.
(*Director, Rev. W. Sidgreaves, S.J.*)

The solar surface has been observed on 217 days, and 133 drawings have been made. Of these there are 114 showing spots and faculæ, and 19 showing faculæ only; and on 84 of the observing days the surface was found to be completely free from spots and faculæ.

At the time of writing our last report our radio-telegraphic receiver was working well, and we expected to obtain the correction to our longitude as closely as our transit instrument could give us our local time. But the local time has been our difficulty. The instrument is a very old one, and has serious faults. Many nights have been devoted to experiments for overcoming these, and a full account will be given of them in our "Annual" of results. The work was progressing favourably, and we had reason to think that the difficulties were already surmounted, when the order came shutting down our radio-installation, and we have to await better times for confirmation of the experimental trials, which give our accepted longitude nearly 0.4 sec. too great westerly.

A great deal of time was spent by all the Observatory staff in the preparation for the total solar eclipse of August 21. Two cœlostats and long and short focus cameras were erected and adjusted. The eclipse was successfully observed at Hernösand, in Sweden.

Accordingly, no work in the spectra of Sun-spots was attempted with the large grating spectrograph. The spectra of two spots were observed visually, and were found to maintain the constant character, which has persisted since 1882.

With the Whitelow camera exposures have been made on the spectra of the nebula in Orion, and a few other nebulæ. One plate was secured of the spectrum of Delavan's comet, and also a few direct photographs of the comet. The spectrum of α Andromedæ was photographed with the Thorp prism. The transit of Mercury 1914 Nov. 6-7 was successfully observed both visually and with the spectroscope. A good deal of work has been done on the relation between areas of long-continued solar disturbance and magnetic disturbances.

The continuous records of the meteorological instruments and of the Milne seismograph have been in good condition throughout the year. Weekly returns of the former have been sent regularly to the meteorological office, and of the latter monthly statements of disturbances have been sent to the central seismic station at Shide.

Wolsingham Observatory (Rev. T. E. Espin's).

The 17 $\frac{1}{4}$ -in. was dismantled in May, and the new 24-in. made by Calver was erected in September, consequently there has been very considerable interruption in observing. The new 24-in. is of very fine figure, and though of great weight, is carried quite well on the old stand. The Observatory itself has been rebuilt in the course of the summer. The examination of the stars in zone +45° has been completed during the year, and in zone +44°, R.A. 8^h to 15^h and 19^h to 0^h, have also been finished. The new double stars have been communicated to the Society. The 24-in. has also been employed in the re-examination of certain red stars where the classification of type was uncertain. The results will in due course be communicated to the Society.

Mr. D'Esterre's Observatory, Tatsfield, Surrey.

The programme of work mentioned in previous reports has been continued. Photographic records have been obtained on 84 nights during the year as follows:—

15-inch reflector, 225 plates, average exposure 20 minutes.

Portrait lenses, 568 plates, „ „ 22 „

Exposures on the region of the North Pole (*Harv. Circ.*, 170) give the following data relating to penetrating power:—

				m
15-in. reflector, Exp. 5 min., mean of 4 plates on 3 nights, limit				15.5
	10	11	7	16.0
	15	15	11	16.6
	20	17	15	17.3
	40	5	5	17.9
6 $\frac{1}{2}$ -in. Voightländer	20	12	12	14.8
	40	4	4	15.1
3 $\frac{1}{2}$ -in. Dallmeyer	20	11	11	14.0
	40	4	4	14.7

Observations of the new variable stars 7, 12, 25, 26, 86, 92, 93, 94, and 95, 1914, were published in *A.N.*, 4718, 4720, 4738, 4747. The following data relate to other new variable stars observed during the year:—

- (a) 1914 Cassiopeiae (1855), 0^h 56^m.8 + 60° 59'.5. Max. 10^m.6. Min. 11^m.9. Compan. dist. 13'', pos. ang. 210°, mag. 15.4. Photo. obs. 102. Vis. obs. 1. Colour orange. Period irregular.

- (b) 1914 Cassiopeiæ (1855), $1^h 3^m.5 + 60^\circ 27'$. Max. $11^m.3$. Min. $12^m.6$. Compan. dist. $16''$, pos. ang. 20° , mag. 15.0 . Photo. obs. 100:—1911 Aug. to 1914 Sept. Vis. obs. 1. Colour sli. yellow. Period irregular.
- (c) 1914 Cassiopeiæ = B.D. $+59^\circ 335$ (1855), $1^h 41^m.2 + 59^\circ 9'.8$. Max. $10^m.5$. Min. $12^m.0$. Compan. dist. $27''$, pos. ang. 115° , mag. 14.1 . Photo. obs. 182:—1911 Aug. to 1914 Sept. Vis. obs. 1. No decided colour. Period 6.2 days, but not perfectly regular.
- (d) 1914 Persei (1855), $2^h 17^m + 58^\circ 15'$. Max. $11^m.6$. Min. $13^m.0$. Photo. obs. 280:—1911 Aug. to 1914 Oct. Vis. obs. 4. No decided colour. Period about 5 days.
- (e) 1914 Persei (1855), $2^h 28^m.4 + 55^\circ 8'$. Max. $12^m.1$. Min. $14^m.0$. Compan. dist. $17''$, pos. ang. 180° , mag. 16.9 . Photo. obs. 278:—1911 Aug. to 1914 Oct. Vis. obs. 6. Colour decidedly red. Period irregular.
- (f) 1914 Persei (1855), $2^h 58^m.6 + 52^\circ 37'$. Max. $11^m.9$. Min. $13^m.2$. Photo. obs. 48:—1911 Sept. to 1914 Sept. Vis. obs. 6. Colour bluish. Period short and probably irregular.
- (g) 1914 Aurigæ (1855), $4^h 55^m.8 + 47^\circ 24'$. Max. $11^m.5$. Min. $12^m.6$. Photo. obs. 41:—1911 Oct. to 1914 Sept. Vis. obs. 3. Colour pale red. Period long, irregular.
- (h) 1914 Lyræ (1855), $18^h 19^m.2 + 39^\circ 1'$. Max. $13^m.7$. Min. $15^m.0$. A double star components $16^m.7$, $16^m.8$, dist. $6''$, lies at pos. ang. 115° , dist. $31''$. Photo. obs. 115:—1911 May to 1914 Oct. Vis. obs. 4. No decided colour. Period about 7.23 days.
- (i) 1914 Lyræ (1855), $18^h 49^m.5 + 46^\circ 30'$. Max. $11^m.9$. Min. $13^m.4$. Compan. dist. $15''$, pos. ang. 230° , mag. 17.0 . Photo. obs. 37:—1912 May to 1914 Sept. Vis. obs. 1. Colour red-orange. Period long, irregular.
- (j) 1914 Lyræ (1855), $18^h 59^m.8 + 27^\circ 50'$. Max. $11^m.5$. Min. $< 16^m.1$. Compan. dist. $15''$, pos. ang. 320° , mag. 13.3 . Photo. obs. 58:—1911 Aug. to 1914 Oct. Vis. obs. 3. Colour dull red. Period 270 days.
- (k) 1914 Lyræ (1855), $19^h 4^m.7 + 27^\circ 36'$. Max. $11^m.6$. Min. observed $17^m.0$, min. from the light curve $17^m.3$. Min. after max. 130 days. Photo. obs. 63:—1911 Aug. to 1914 Oct. Period 240 days.
- (l) 1914 Lyræ (1855), $19^h 5^m.8 + 27^\circ 59'$. Max. $12^m.3$. Min. observed $< 17^m.3$, probable min. from light curve, about $18^m.5$. Min. after max. about 150 days. Photo. obs. 62:—1911 Aug. to 1914 Oct. Period 270 days.
- (m) 1914 Cygni (1855), $19^h 18^m.2 + 29^\circ 24'$. Max. $9^m.4$. Min. $11^m.2$. Photo. obs. 93:—1911 Aug. to 1914 Oct. Vis. obs. 3. Colour near min. pale red. Period long, irregular.
- (n) 1914 Cygni (1855), $19^h 33^m.1 + 28^\circ 11'$. Max. $10^m.4$.

Min. $12^{\text{m}}.1$. Compan. dist. $14''$ and $17''$, pos. ang. 265° and 130° , mags. 17.3 and 17.4 . Photo. obs. 63:—
1911 Aug. to 1914 Oct. Vis. obs. 6. Colour deep red-orange. Period about 280 days. Min. after max. about 200 days.

- (o) 1914 Ursæ Minoris (1855), $21^{\text{h}} 21^{\text{m}} + 87^\circ 43'.4$. Max. $> 12^{\text{m}}.8$; max. from light curve $12^{\text{m}}.5$. Min. $18^{\text{m}}.4$. Min. after max. about 220 days. Photo. obs. 94:—
1913 Mar. to 1914 Oct. Vis. obs. 4; brighter vis. than phot. around $15^{\text{m}}.5$. Period about 340 days.

Amongst a mass of additional observations of objects previously discovered, the following are of interest:—

- 87, 1911 Persei (*Harv. Circ.*, 176). The max. of 1911 Nov. 13 was $11^{\text{m}}.1$ on the Harv. scale. The object was again observed bright in June 1914:—

	h		
1914 June 15	12.4	Var. mag. 16.8	} 11 plates.
27	12.7	12.6	
29	12.2	13.0	
30	12.9	15.5	

On June 28 and 29, visually with the reflector pr. 200, the var. was clearly vis., but decidedly fainter visy. than photoy.: on June 30, prs. 200 and 350, it was invis., although all compar. stars down to photo. mag. 15.6 were vis. The period indicated by 312 photo. and 22 vis. obs.:—
1911 Aug. to 1914 Oct., is 950 days, during 930 of which the magnitude varies hardly perceptibly around 16.9 .

- 2, 1913 Cassiopeiæ. The period is 520 days. Max. on Harv. scale $11^{\text{m}}.4$. Min. $< 18^{\text{m}}.2$. Compan. dist. $6''$, pos. ang. 120° , mag. $18^{\text{m}}.1$. The min. previously given is in error, as the compan. was mistaken for the var.: the data available make it probable that the actual min. is as low as mag. 21. The period is not a submultiple of that given above.

- 25, 1914 Herculis. Min. observed $17^{\text{m}}.0$; from the light curve $17^{\text{m}}.1$. Min. after max. 180 days.

- 95, 1914 Cephei. The description of the light curve below $15^{\text{m}}.0$ in *A.N.* 4770 is in error, and in the tabulated observations plates V. 439, 570, 653, should read Var. invis. A good series of reflector plates obtained since announcement follow the var. down to $18^{\text{m}}.3$, and the actual minimum from the light curve is $18^{\text{m}}.5$ at 190 days after max. The form of the curve is closely similar to that of 7, 1914 Cassiopeiæ.

The general conclusions (1) to (5) mentioned in my last report are on the whole confirmed, and now rest on the basis of 2326

plates covering 53 regions of which the 26 best observed are covered by 1952 plates:—

- (1) This conclusion is the reverse of what might be expected were the fainter stars inherently red:—*Ap. J.*, vol. xl. No. 2, p. 187. The region around β Cygni is exceptionally rich in faint variables, and any general conclusion based on this region alone would be entirely misleading.
- (3) This requires some modification. Four variables are now known whose minima fall between $18^m.0$ and $19^m.0$, and one which probably goes to mag. 21. They are all long-period variables of marked regularity, red around maximum, and varying through six or more magnitudes. No other type of variation is known amongst stars of this faint order of magnitude.

Mr. A. M. Newbegin's Observatory, Wallington, Surrey.

In submitting the first report of this observatory it may be well to state that the instrumental equipment consists of a $6\frac{1}{4}$ -inch Cooke photovisual, equatorially mounted, and a 3-prism Evershed spectroscope by Hilger.

During the year 1914 observations for solar prominences have been made. The results are given in tabular form:—

Number of observations	= 141
prominences	= 725
Daily average	= 5.14

These were distributed as follows:—

Number of prominences on N. hemisphere	= 375
S. "	= 350
E. limb "	= 378
W. "	= 347

No prominences less than $30''$ in height have been recorded.

It is noteworthy that the preponderance of prominences in the first half of the year was reversed; that is to say, the southern hemisphere and the west limb had the greater number.

Metallic prominences have been recorded on fifteen occasions, and the chromosphere has been seen many times in *b* group.

Observations of the spectrum of Sun-spots have also been recorded.

Mr. G. J. Newbegin's Observatory, Lyndale, Sutton, Surrey.

During the year 1914 seventy-one observations for solar prominences were made, of which number three only gave no results.

The remaining sixty-eight yielded a total of 238 prominences. Of these 153 were classified as bright and 85 as faint. The

bright are undoubtedly of greater strength than those of 1913, and on May 16 (civil time) in the forenoon there was one most brilliant prominence. The mean daily average works out at 3'35.

Delavan's Comet developed considerable brightness of nucleus and of tail also: the latter being discernible in the telescope within four nights of full moon, but only by moving the telescope in R.A.

Rousdon Observatory, Devon.

(Sir Wilfred Peek's; Mr. C. Grover, Observer in charge.)

The building is kept in good repair, and the instruments are in perfect working order. Weather has been very favourable, and considerable more work has been done than was possible last year. Observations have been made on 142 nights. August, September, and October were three good observing months. Observations of the long-period variable stars were continued exactly as in former years, and 384 magnitudes were recorded, making a total of 12,459 magnitudes during the 29 years this work has been in progress. 462 maxima and 339 minima have been observed.

The partial solar eclipse on August 21 was well seen. About noon, at time of greatest obscuration, a distinct gloomy shade came over the landscape, and the trace of the Campbell sunshine recorder dwindled to a narrow line and again increased as the eclipse passed away. At the eclipse of 1905 August 30, when considerably more of the Sun was covered, the sunshine record very nearly ceased, although the sky was quite clear.

The transit of Mercury on November 7 was observed throughout. At ingress a minute segment was seen encroaching on the Sun, and, when bisected, the curve was distinct; when fully on the disc the planet was clearly defined, perfectly circular, and very black. An image of the Sun, five inches diameter, was projected on a white card and the place of the planet was marked at 10 and 11 a.m., noon, and 1 and 2 p.m. At egress, when the limb of the planet was nearing the edge of the Sun, a black ligament shot across the intervening light space, and was repeated two or three times till actual contact, when it passed to bisection, and the last segment was seen leaving the Sun clear and black, with power 310.

Delavan's Comet (1913 *f*) became visible to the naked eye at the end of August, gradually increasing in brightness during September and October as it slowly travelled along the northern sky below the Great Bear. It was best seen with a distinct tail when near Cor Caroli on October 9, and was last seen here November 6, nearly midway between Arcturus and α Coronæ. Encke's Comet (1914 *d*) was traversing the northern sky at the same time, and on October 17 was a faint and diffuse nebulousity in the equatorial telescope. Lunt's Comet (1914 *e*) was also observed coming up from the south. It was a very distinct telescopic object, but not seen here by the naked eye.

Observations of stars with the transit instrument are frequently taken for the regulation of the sidereal clock. The usual meteorological observations have been regularly continued.

The Rev. T. E. R. Phillips' Observatory, Ashted, Surrey.

The usual observations of planets and comets have been continued.

The recently accelerated velocity of Jupiter's equatorial current has been on the whole maintained, and the Red Spot, on its emergence from the dark material of the S. Tropical Disturbance, was found to have regained much of its former distinctness. Its longitude at the date of opposition (August 10) was $202^{\circ} \pm$ (sys. ii.), and it continued to diminish steadily.

A systematic comparison of the brightness of Iapetus with the neighbouring stars was made during the earlier months of the year with the $12\frac{1}{4}$ -inch Calver reflector, and a number of double stars of special interest have been measured with the 8-inch refractor belonging to the Society.

Owing to removal to another residence, the Calver equatorial had to be dismounted in September.

During the year the light curves of 21 long-period variables published by the B.A.A. have been investigated, and it is hoped the results will be ready for printing shortly.

The meteorological observations have been continued as in former years.

Mr. Reynolds' Observatory, Harborne, near Birmingham.

During the year the 28-inch reflector was employed in photographing the brighter globular clusters with graduated exposures to test the point raised some years ago by Dr. Isaac Roberts as to the presence of nebulosity in the clusters.

In the cases of N.G.C. 6205 and 5024 no certain signs of nebulosity were discovered, and if any is present its brightness is insufficient to come out with short exposures, while with long exposures the central portion of the clusters is too dense to differentiate satisfactorily between nebulosity and star images. In the case of N.G.C. 7078, however, a few minutes' exposure brings out a nebulous nucleus, apparently without any star images. Exposures of 20 minutes show this nucleus studded with small star discs, and in negatives of an hour's exposure all trace of the nebulous nucleus is blotted out.

Some thousands of measures of density and position have been made with the photomicrometer for the photometric chart of the Huyghenian region of the Orion Nebula, referred to in the last Annual Report.

Helwân Observatory, Egypt.

(Superintendent, Mr. H. Knox Shaw.)

[The Observatory is attached to the Physical Service of the Survey Department: Director, Mr. B. F. E. Keeling.]

Time-Service.—The time-service has been maintained as usual.

During the first five months of the year the Riefler clock was in the hands of the makers at Munich, as it was not found possible to cure the fault in the escapement which had shown itself in the previous year. Since its return it has been running extremely well.

Reynolds Reflector.—The telescope was used on 105 nights, and 138 plates were exposed during the year:—

41	plates on	28	nebulae
18	„ „	J VIII	
24	„ „	stars of large proper motion	
9	„ „	6 magnitude fields	
8	„ „	the North Pole	
16	Hartmann test-plates		
22	miscellaneous plates.		

In addition, eighteen photographs were taken with the prismatic camera, chiefly for the purpose of testing various brands of plates. The photographs were taken by Mr. Knox Shaw, except those in July and August, which were taken by Mr. Eckersley.

During October and November the new 30-inch mirror by Ritchey (presented by Mr. W. W. Astor), with a new cell for it also by Ritchey, and, in addition, a new fork, which enables the telescope to be turned into any declination (presented by Mr. Reynolds), were mounted. The telescope has been considerably improved thereby, but it is too early yet to make any definite statement as to its powers.

A series of tests by the Hartmann photographic method was carried out on the old 30-inch mirror, and the results published along with those of similar tests carried out by Mr. W. S. Adams on the new mirror before it left Pasadena.

The series of magnitude plates taken at the request of the Astronomer Royal has been completed.

Nine positives of nebulae have been presented to the Royal Astronomical Society.

Radiation.—Observations with an Ångström pyrheliometer have been made three times daily on fine days throughout the year. A preliminary discussion of some of the results has been made by Mr. Eckersley, and is in the press. Considerable modifications in the programme of observations will be made in 1915. In particular it is intended to make observations also through a green absorption screen which has been procured from Upsala.

Transit of Mercury.—The transit was observed with the 4-inch equatorial in good weather.

General.—Mr. T. L. Eckersley left the Observatory in November to undertake military duties. His place has been taken by Mr. E. W. Bliss. The usual meteorological, seismological, and magnetic observations have been made. Bulletins Nos. 11, 12, and 13 were published during the year.

Nizamiah Observatory, Hyderabad, Deccan.
(Director, Mr. R. J. Pocock.)

In 1913 June the Astrographic telescope was dismantled in order that parts might be sent to England for repairs, and that a new 10-inch guiding telescope might be constructed by Messrs. T. Cooke & Sons.

The new parts only reached Hyderabad on 1914 May 2. The telescope was erected immediately, and observations for the adjustment of the telescope commenced. Work was then delayed for three months till the end of September owing to the unusually heavy monsoon.

During the last three months of the year, however, plates have been obtained without much interruption, a total of 130 plates having been obtained with the 8-inch Cooke photovisual, the longest exposure being usually 15 minutes, a considerable number of which have been passed as good enough for measurement for the Astrographic Catalogue. The measurement and reduction of these plates is proceeding.

A good deal of computation of Standard Co-ordinates, etc., has been carried out in connection with the Astrographic Catalogue, and some plates taken at the University Observatory, Oxford, are being measured with a view to determining proper motions.

Transit observations for determining the time have proceeded regularly. The erection of the 15-inch Grubb visual telescope has been postponed for the present.

Steady progress with the Astrographic Catalogue is anticipated during the coming year.

Kodaikānal and Madras Observatories.
(Director, Mr. John Evershed.)

The Director was away on a deputation to New Zealand during January and February, Dr. Royds officiating. Early in the year the Government of India sanctioned a three months' expedition to Kashmir to test the suitability of the climate for solar research, and at the end of April the Director and Mrs. Evershed again left Kodaikānal to take up this work.

The very remarkable conditions which had been observed during a holiday tour in Kashmir in August and October 1913

were found to hold also in the months of May, June, and July 1914, and the fact was considered to be established that in a well-watered plain, surrounded at no great distance by high mountains, the conditions as regards solar definition are vastly superior to those experienced in more open localities or on mountain tops. The conditions in the enclosed valley of Kashmir would seem, in fact, to be the reverse of those experienced on an exposed mountain top; for instead of the definition passing from bad to worse as the Sun rises higher in the sky, as is commonly the case at Kodaikánal and other mountain stations, it was almost without exception found to progress from good to better in Kashmir, reaching the best definition between the hours of 2 and 3 p.m. The detailed report of this expedition has been issued as Bulletin No. lxii.

During the Director's absence the usual routine at Kodaikánal was effectively carried on under Dr. Royds, and about the normal number of solar photographs and spectroheliograms were obtained during the year. No H α spectroheliograms were, however, secured, as the large Michelson grating was required for use in the spectrograph for special researches for which the smaller Rowland grating was not so well suited.

A new measuring apparatus was constructed in the Observatory workshop for dealing more accurately with the prominence plates. This was brought into use on October 1, and from that date onwards detailed observation of the forms and position angles of the prominences at the telescope was discontinued, as all the required data can be much better determined from the photographs. Visual work with the spectroscope may now be concentrated on the observation of phenomena which cannot be readily photographed, such as displacements of the hydrogen lines in prominences and Sun-spots, and temporary eruptive prominences on the disc or at the limb.

With the large grating spectrograph Dr. Royds has continued his researches on the displacements of unsymmetrical lines in the electric arc, and he has succeeded in explaining the anomalous shifts of many of the solar lines as due to density conditions in the arc which are not present in the Sun. Although the discovery of this density effect in the arc has complicated the whole subject of the shifts of the arc lines under pressure, and the comparison of arc and solar wave-lengths, it promises to lead to a distinct gain in our knowledge of solar conditions, not only by explaining the apparently anomalous shifts of some of the solar lines when compared with the arc, but also by indicating the extreme tenuity of the solar gases, the combined partial pressures of which appear from independent considerations to be less than 1 atmosphere.

In Bulletin No. xxxix. the displacements of the spectrum lines at the Sun's limb are discussed, and the reasons given for the conclusion that the line shift is not due to a pressure difference between the effective regions of absorption at the limb and at the centre of the disc. In continuation of this research the displacements are now being measured, not only at the limb but at

numerous points between the limb and the centre. With a small solar image on the slit plate, spectra 28 mm. in width are obtained, representing sections of the entire disc from limb to limb. Many of these plates have been measured, and the results so far promise very interesting conclusions.

An important addition to the equipment of the Observatory is a new grating of 75,085 lines, ruled by Prof. Anderson on Rowland's engine. This was received in September, and no time was lost in mounting it in the large spectrograph. This grating is the most perfect the Observatory possesses, and it is now used in all researches where high resolving power is required.

A new positive on negative spectro-comparator, constructed by Hilger from designs by the Director, was received during the year, and has proved most efficient for measuring small displacements of spectrum lines. One of the ordinary Hilger micrometers has also been modified, so as to measure by the positive on negative method the very wide spectra obtained for determining the rate of change of wave-length of the iron lines in passing from the centre of the Sun's disc to the limb.

In all the research work the members of the Indian staff, Messrs. Sitarama, Nagarajan, and Narayanan, as well as Mr. Krishna, the photographic assistant, have ably co-operated in taking and measuring the plates and in the computations necessary in the reductions. Mr. Narayanan has also investigated the question as to whether the lines which are specially sensitive to density in the arc are also affected by relative displacements at the limb of the Sun. His results have been published in Bulletin No. xlv.

The meteorological and seismological observations were continued as in former years.

Publications.—Eleven Bulletins have been issued during the year, Nos. xxxiv. to xlv. inclusive. No. xliii. had not been distributed at the close of the year.

At Madras the time service was maintained as usual. A new micrometer for the transit instrument was installed in July; this is fitted with a ruled glass reticle in place of spider threads.

The Dominion Observatory, Ottawa.
(Director, Dr. W. F. King, Chief Astronomer.)

Astrophysics.—Although visual observations of double stars with the 15-inch refractor were continued during the first half of the year, the principal work with the telescope has, as hitherto, been the spectroscopic determination of radial velocities, especially of spectroscopic binaries. Although only one orbit has been completed during the year, there are seven other binaries for which the periods are determined, and of which orbits will be completed within the next two or three months.

The dome for the new separately mounted photographic tele-

scope was erected in July last, and the telescope brought into use. It consists of an 8-inch stellar camera of 42 inches focus, a 6-inch of 32 inches (both objectives by Brashear), and a wide angle camera $3\frac{1}{2}$ inches aperture and 12 inches focus.

There are two 8-inch aperture objective prisms of angles 15° and 25° , which can be readily attached to the 8-inch camera. The guiding telescope of 5 inches aperture is adjustable, and can be inclined in any desired direction up to about 7° away from the optical axes of the camera for convenience in comet photography. This telescope is to be used for stellar and comet photography, for qualitative spectroscopic work, and for photographic photometry.

Observations with the cœlostast telescope and grating spectrograph on the solar rotation and allied problems have been actively continued during the past year. Two series of rotation plates in the special region at $\lambda 5600$ and the general region at $\lambda 4250$, made in 1913, have been measured and reduced. These series agree very closely with each other, but give a value lower than those obtained in 1911 and 1912 by about one and a half per cent. It has not yet been determined whether this is due to a systematic instrumental error, to a change in the habit of measurement, or to a variation in the rate of rotation.

The large glass casting for the main mirror of the 72-inch reflecting telescope was received at the shops of the J. A. Brashear Co. in August, and the grinding of the edge and central hole is completed and that of the surfaces is under way.

The casting, which appears to be practically perfect, was $73\frac{5}{8}$ inches diameter, $13\frac{5}{8}$ inches thick, and weighed 4960 lbs. The work on the mounting of the telescope is well advanced, and it is expected to be completed next October.

The investigation as to the most suitable site in Canada resulted in favour of the region immediately around Victoria on Vancouver Island. The astronomical conditions are such that more than twice as much work, and of better quality, can be done there than at Ottawa. The Government therefore decided to locate the telescope near Victoria, and 50 acres of land around the summit of Saanich Hill, of 732 feet elevation, about 8 miles north of Victoria, were purchased.

The water supply and the road are being arranged for, and building construction will begin early in the spring. It is hoped that the instrument will be mounted in its dome in the year 1915.

Department of Geophysics.—This branch of the Observatory comprises Seismology, Terrestrial Magnetism, and Gravity. The equipment of the three branches consists of the same instruments as reported in 1912. Monthly bulletins of the recorded earthquakes are issued as heretofore, and the stations to which the bulletins are sent have been increased to 87, distributed over the world. During the calendar year 76 earthquakes have been recorded, amongst which was a local one, which, although not destructive, yet was felt over an area of 200,000 square miles. Investigations made here for some years have definitely associated microseisms with areas of

low barometer on the Atlantic ocean along or near the coast line of the United States and Canada. The period of the microseisms is being correlated with the period of the ocean waves by means of an undagraph exposed to the open ocean at Chebucto, near Halifax.

An investigation of 465 earthquakes recorded here shows that the influence of the moon and sun, singly or jointly, in creating difference of stress upon the earth, is not sufficient to make itself marked in "firing" or "setting off" earthquakes.

A waterproof cement vault, 23 feet beneath the surface, 21 by 9 by 7 feet, has been built adjoining the Observatory, now ready for installation of the instruments for the study of the deformation of the earth under the influence of the moon and sun, undertaken by the International Seismological Association.

The magnetic survey of Canada was continued, and 36 stations were occupied, at each of which the three elements—declination, inclination, and intensity—were obtained. We have now one series of magnetic stations, with intervals of about 25 miles, across the continent from the Atlantic to the Pacific.

Gravity observations with the half-seconds pendulum (3) were resumed, and 18 stations were occupied in eastern Canada, besides Washington, whereby the results are correlated with those in Europe.

Meridian Observations. — Observations with the meridian circle were made on 126 nights. On 101 nights the work was devoted to the list of latitude stars which has been under observation for several years; the number of observations obtained was approximately 2000 for right ascension and 1800 for declination. Two observers were engaged throughout the year, and two others for shorter periods.

The regular programme of astronomical field-work comprised the determination of the latitudes and longitudes of fourteen stations, seven of these being in British Columbia, and seven in Quebec. Kamloops, one of the stations in British Columbia, was used as a longitude base for the remaining six, it being first determined from Field, B.C., the previous base station. The longitudes of the stations in Quebec were determined from Ottawa. 3-inch Cooke transits, with registering micrometers and latitude levels, were used for the field observations; personal equations were determined as usual.

The longitudes of four stations in northern Quebec, where no telegraph line was available, were determined by wireless telegraphy. For this purpose the time-signals sent out by the U.S. wireless station at Arlington, Va., were utilised as a means of comparison between the observer's chronometer and the Observatory sidereal clock, thus replacing the usual "arbitrary signals" transmitted over the telegraph line for the same purpose. To effect the comparison, a break-circuit chronometer, rated to gain about ten minutes per day, was caused by a suitable arrangement to beat in the telephones of the wireless receiving set at the same time that the wireless time-signals were being received; by

noting the times at which coincidences occurred, it was found possible to make comparisons to within about $\cdot 01$ second. This being done at both the field station and the Observatory, a direct comparison of clocks was effected, independent altogether of the accuracy of the Arlington signals. The transportation in the field was effected by canoe; the receiving aerials were erected on trees, ground connections being made in running water wherever possible. The telescope used was a portable broken-type transit by Heyde, fitted with registering micrometer and latitude level. The few preliminary computations made indicate that the results will be satisfactory.

The time-service has been maintained as in previous years. About 325 electrically driven clocks are operated in the various government buildings by means of several secondary master-clocks continuously synchronised from the Observatory by the method mentioned in a previous report. In addition, relays beating seconds are maintained in several offices in the city, time-signals are sent out by telegraph and telephone; the time is recorded on the various seismographs, and a time-ball is dropped on Parliament Hill.

Adelaide Observatory, South Australia.
(*Director, Mr. G. F. Dodwell.*)

The outstanding feature of the year was the visit of the members of the British Association for the Advancement of Science. Amongst those who visited this Observatory were Sir Frank Dyson, Astronomer Royal, Professors H. H. Turner, A. S. Eddington, J. W. Nicholson, E. W. Brown, C. G. Abbott, A. D. Ross, and Mr. Michie Smith. Amongst other helpful suggestions which resulted from their visit, that of the appointment of a Board of Visitors has been recommended to the Government for adoption at the present time, and it is hoped that others may also be carried into effect when the war is over.

Meridian Service.—The transit circle was used throughout the year for the observation of the intermediate stars of the Sydney zone (-52° to -64°). The observations were reduced from day to day by the aid of graphic reductions, which considerably lessened the labour of computing. The fundamental stars in the zone were used for the daily time service. The time-ball at the semaphore was dropped at 1 p.m. daily, except on Sundays, and a few occasions when telegraphic communication was temporarily suspended. The ordinary system of distributing time signals to country telegraph stations and various Government departments was continued. A new Rieller vacuum case sidereal clock of the first class was ordered in the beginning of the year, and arrived in July. It is now installed in the transit room, and at a later date it will be sheltered by a clock case in which a temperature control will be maintained.

Field Work.—Latitude and longitude stations were established in the early part of the year at Mount Lofty Summit, Mannum, and Palmer. An interesting piece of field work, which was undertaken by co-operation between this and the Melbourne and Sydney Observatories and the Commonwealth Department of Lands and Surveys (Director, Mr. C. R. Scrivener), was the determination of latitude and longitude at Port Augusta and Bookooloo on the East-West Transcontinental Railway Survey. This was carried out during the last week in July and the first week in August. In addition to the usual exchange of longitude signals on the land lines, wireless telegraphy was also used, with successful results. Clock beats were transmitted from both Melbourne and Adelaide Observatories through the respective wireless stations, by courtesy of the Commonwealth Engineer for Radio-telegraphy, and were recorded at all three Observatories and at the two field stations, the method of coincidences being used. At the field stations a portable wireless receiving apparatus was used, with light sectional masts, each 36 feet high, and the time observations were made by Mr. Vance of the Commonwealth Survey and the Director of this Observatory, both using the almucantar method as adapted by Cooke, Mr. Vance using an excellent 10-inch Repsold theodolite. Transits were recorded with the push-button on a chronograph. The services of a land line and wireless operator were available at both stations, and personal and instrumental equation was afterwards determined by Mr. Vance at Adelaide, Melbourne, and Sydney. In addition to the latitude and longitude determinations, a set of magnetic observations was obtained at both stations, for which a Carnegie magnetometer and Barrow dip circle were used.

From the end of August till the middle of November the Director was associated with the Musgrave Range Geological Survey Expedition, and carried out a programme of magnetic observations near that portion of Central Australia, supplementary to those made by the Carnegie Institution in other parts of this State. Latitudes and longitudes were also determined at the main camps by the almucantar method, the portable wireless receiving outfit used at Port Augusta and Bookooloo being employed for the reception of longitude signals, which were sent out by Adelaide at 9 p.m. each evening till the return of the expedition. The attempt was successful, the longitude signals being heard distinctly at the farthest main camp, between 650 and 700 miles in a direct line from Adelaide, as well as at other intermediate places.

Gravity Survey and Latitude Variation Work.—In connection with the field work, which now forms a regular part of the Observatory programme, it had been decided to include field gravity determinations with the other operations, and a pendulum apparatus similar to that used by the Survey of India was placed on order at the beginning of the year. The apparatus was being made under the supervision of the International Geodetic Bureau,

when the war broke out, and it is consequently not now available. A request was received from the International Bureau some time ago that latitude variation observations might be made at Adelaide in conjunction with La Plata, the two Observatories being situated almost exactly on the same parallel of latitude and almost half-way round the globe from one another. It is hoped that this work may be commenced at a later and more favourable opportunity.

Seismology.—The Milne seismograph was continuously at work during the year, and the tabulated records were sent as usual to the Shide Observatory, Isle of Wight.

Miscellaneous.—The 8-inch Cooke equatorial was used for miscellaneous observations, and regular use was also made of it on certain nights by members of the South Australian Astronomical Society, principally for variable star observations. A fine life-size oil portrait of the late Sir Charles Todd, who was for over fifty years Government Astronomer at Adelaide, was presented to the Observatory by the family, and has been placed in the transit room.

Public visits were made to the Observatory on practically every Friday evening during the year, and occasional lectures on astronomy were given at country institutes and other places.

Perth Observatory, Western Australia.
(Acting Director, Mr. H. B. Curlewis.)

Meridian Observations.—The smallness of the staff and the urgent necessity for completing the Astrographic Catalogue have practically limited work on the Transit Circle to time determinations, 490 clock stars having been observed on 190 nights.

Astrographic Catalogue.—Steady progress has been made, and another zone, namely 34° S., has been completed. Following out the original plan, this has been published in four separate volumes. The measurements and reductions of zone 36° are also well advanced, and, barring accidents, the whole of this zone will be finished by the end of next year. This progress may be considered very satisfactory, and is mainly due to a skilled and experienced measuring staff, in which, fortunately, there has been no change for over two years. All the volumes published during 1914 will be distributed shortly. During the year several batches of bad plates were found, and many of these had to be rejected. No further Bulletins of Double Stars will be issued until the Catalogue is completed. The Acting Director takes this opportunity of gratefully acknowledging the assistance and advice kindly given by the Astronomical Members of the British Association on the occasion of their visit in August.

Seismology.—The Milne seismograph registered continuously

throughout the year, and a record of all disturbances was forwarded monthly to the Seismological Committee, England. Copies of some of the records, on the advice of Professor Turner, were forwarded to Mr. Burgess for examination, and valuable and much-appreciated information was obtained in reply.

The Tides.—During the year the Harmonic Analysis of the Port Hedland (N.W. Coast) tides for 1913 was made out, and the constants forwarded to England and America.

It was hoped that the predicted figures for 1915 would come to hand in time for publication; but, unfortunately, such did not happen, so it became necessary to make out tables based on rough constants determined from an analysis of the figures for the last five months of 1912. The tables for 1914 were based on the same constants and gave every satisfaction, so that the 1915 tables are expected to be sufficiently accurate for shipping purposes.

When halfway through the compilation of the 1914 figures, the services of the computer had, unfortunately, to be dispensed with, and it is therefore doubtful when the tidal constants will be determined. It was very annoying, as the constants from the 1914 records were required as a check on those for 1913.

Time Service.—The time-ball at Fremantle failed on 22 occasions, which is considerably more than last year, but 15 of the failures occurred in September and October, when the new telephone system was being introduced. On two occasions the ball was not hoisted, and the remaining five failures were due to line faults. A daily check on the time of ball-drop was kept, and only five times did the error exceed a tenth of a second.

The Observatory is not yet connected by wireless with Applecross, though the matter is under consideration.

Miscellaneous.—The partial lunar eclipse of September 4 was observed and also the commencement of the transit of Mercury on November 7.

Westland's Comet was observed during September and October. From precise determinations on five nights in the latter month Professor Ross worked out the comet's orbit. A photograph taken on September 22 showed two distinct, though short tails.

Photographs of some of the well-known nebulae and star clusters, as well as of the Moon, were also taken during the year.

The interest taken by the public in observational astronomy still keeps up, for over eleven hundred visitors were received on 92 nights. Occasional lectures were given, and a considerable amount of astronomical information supplied to the press, including tables of rising and setting of Sun and Moon, and a monthly star chart to one of the weekly papers.

Interest in the Western Australian Astronomical Society is still sustained.

Union Observatory, Johannesburg.
(*Director, Mr. R. T. A. Innes, Union Astronomer.*)

Instrumental Equipment.—This remains unaltered. The twin 6-inch and 7-inch refracting telescope presented by the late Mr. J. Franklin-Adams, has now been erected in a substantial building fitted with a dark room. The discs for the 26-inch refractor are not yet delivered to Sir Howard Grubb, so that the hope expressed in the last report that the instrument might be erected in 1914 has not been realised.

9-inch Refractor.—Measurements of double stars have been continued, and during the year satisfactory sets have been obtained for 310 pairs, which include Sirius and most of the known southern binary systems.

The phenomena of Jupiter's Galilean satellites have been observed regularly.

Comet 1914 *d* was frequently observed.

2 $\frac{5}{8}$ -inch Talcott Telescope.—Latitude and time observations have been maintained. The results of the first three years' observations (1910 March to 1913 March) for latitude variation have been discussed by Professor Albrecht, and were to have been published during the autumn. Professor Albrecht stated that the results agreed excellently with those of the northern observatories. As the latitude observations made here appear to have fulfilled the purpose for which they were undertaken, they were discontinued after December 21.

Franklin-Adams Twin Telescope.—A number of spectrograms of bright stars have been taken with the 6-inch Cooke photovisual objective and objective prism, using Wratten panchromatic spectrum plates.

Franklin-Adams Star-Camera.—The actual exposures made covered 89 hours, and were chiefly limited to plates for minor planets and comets. The deduced positions of the minor planets found were sent to Dr. Cohn at the Recheninstitut, Berlin, and, on request, to a few other people. Comets Delavan, Zinner, Neujmin, and Westland-Lunt were photographed. With the 6-inch guiding telescope visual observations were made of the phenomena of Jupiter's satellites, of the transit of Mercury, and of the variable star R. Normæ.

Observatory Circulars.—Nos. 10 to 21 were distributed in 1914, and No. 22 is in the Government printer's hands. The chief contents of these circulars are:—No. 10, Third series of double-star measures; No. 11, Places of Comet 1913 *c*, Zinner, and inviting attention to the advisability of adopting astrographic places for comets and planets so as to bring visual practice into conformity with photographic practice; No. 13, Phenomena of Jupiter's satellites; No. 14, Places of Comet 1913 *f*, Delavan; No. 15, Difference of longitude Johannesburg and Lourenço Marques; No. 16, A reference list of photographs obtained with

the Franklin-Adams star-camera; No. 17, List of earthquakes registered since 1910 July; No. 18, Region around η Argûs; No. 19, A list of proper motion stars south of -19° Dec.; No. 20, Upon the use of the stereo-comparator and blink-microscope in examining celestial photographs, and upon the measure of time; No. 21, The transit of Mercury, which was well observed in all its phases; No. 22, Places of Comet 1914 d, Westland-Lunt.

Time-Service, Meteorological and Seismological Observations.—These have continued unchanged. The time-ball at the Bluff, Durban, is dropped by a direct current from the Observatory at noon. A second sidereal clock, Riefler No. 304, has been installed.

Staff.—Mr. Innes, and early in the year Mr. van der Spuy, measured double stars with the 9-inch telescope, but Mr. van der Spuy left to join the Aviation Corps of the Defence Force, and later volunteered for service on the Continent, where he now is. He was succeeded by Mr. E. L. Johnson. Mr. Wood is in charge of the Franklin-Adams star-camera, and Mr. Worssel in charge of the latitude and time observations and the twin telescope. Mr. Simpkins, until he left, and after him Mr. Johnson, assisted Mr. Worssel with the time and latitude observations. Mr. Innes and Mr. Wood took part in the observations of the phenomena of Jupiter's satellites.

Lovedale Observatory, South Africa. (Dr. Alex. W. Roberts.)

As in former years the work of this Observatory has been strictly confined to the observation of variable stars south of -30° Dec.

During the year 2200 observations have been secured, chiefly of Algol stars, or of stars approximating to this type.

The determination of the absolute magnitudes of the comparison stars used in the observations is being proceeded with.

Many stars suspected of variation have been put in the observing list, and it is purposed in future to make the examination of suspected variables a more prominent feature of the work at Lovedale. A large majority of the regular variables have now been observed long enough to yield data for the determination of secular changes in period and other elements.

NOTES ON SOME POINTS CONNECTED WITH THE RECENT
PROGRESS OF ASTRONOMY.*Discovery of Minor Planets in 1914.*

Forty-nine new planets were discovered or first announced in 1914.

Letter and Number.	Date.	Discoverer.	Letter and Number.	Date.	Discoverer.	Letter and Number.	Date.	Discoverer.
TX 775	1914. Jan. 6	L.	UP	1914. Apr. 29	W.	VG	1914. Oct. 15	R.
TY 77	24	W.	UQ 787	20	N.	VH	15	R.
TZ 777	24	W.	UR 788	28	K.	VJ	15	W.
UA 778	25	W.	US	30	N.	VK	15	W.
UB 779	25	N.	UT	Jun. 10	W.	VL	12	W.
UC 780	25	N.	UU 789	24	N.	VM	22	W.
UD	25	N.	UV 791	29	N.	VN	Nov. 9	R.
UE	27	N.	UW	May 1	T.	VO	10	R.
UF 781	25	N.	UX	18	T.	VP	10	R.
UG	22	Me.	UY	Jul. 14	N.	VQ	10	W.
UH	Feb. 28	K.	UZ	31	R.	VR	17	T.
UJ	28	K.	VA	31	R.	VS	21	R.
UK 782	Mar. 18	P.	VB	Aug. 27	P.	VT	21	W.
UL 783	18	P.	VD	Sept. 25	W.	VU	Dec. 19	W.
UM 784	20	Me.	VE	26	P.	VV	22	W.
UN 785	30	Ma.	VF	Oct. 11	W.	VW	22	W.
UO 786	Apr. 20	K.	*	Sept. 25	S.			

The letters stand for: K=Herr Kaiser, Heidelberg; L=M. Lagrula, Nice; Ma=Herr Massinger, Heidelberg (he was killed in battle near Ypres, October 21); Me=Dr. Metcalf, Winchester, Mass.; N=M. Neujmin, Simeis; P=Dr. Palisa, Vienna; R=Herr Reinmuth, Heidelberg; S=Señor J. Comas Sola, Barcelona; T=Herr Thiele, Bergedorf; W=Professor Wolf, Heidelberg. A few doubtful discoveries, to which letters have not been assigned, are omitted above. In the following notes bracketed letters are used thus (KM) to denote the earlier designation by pairs of letters (*i.e.* planets discovered between 1893 May and 1907 September), unbracketed letters denote the second designation (planets discovered since 1907 September). The following planets, unnumbered since the date of the last Report, have since received permanent numbers:—

CZ 755, DC 756, EJ 757, PE 758, SJ 759, SL 760, SO 761,

SQ 762, ST 763, SU 764, SV 765, SW 766, SX 767, SZ 768, TA 769, TE 770, TO 771, TR 772, TV 773, TW 774, NW 790.

The following identities have been established :—

294 = TP, 486 = TJ (probably), 567 = TN, 764 = FD = (KP), 766 = EX, 767 = (JT), 770 = TT, 772 = (KM) = KH, 773 = JS, 774 = FG (probably), 776 = KA, 779 = FA (perhaps), 780 = GH, 781 = BZ, 782 = LZ, 783 perhaps = JM = MO, 787 = KJ, CY = (XR) (probably), 490 = VS (probably), VR = VQ (probably).

The following have been named: 712 Boliviana, 728 Leonis, 758 Mancunia, 771 Libera.

Several planets have been recovered last year; thus VC proved to be identical with 353 Ruperto-Carola, not seen since the year of discovery, 1893. The Trojan planet 659 Nestor was observed at Bergedorf, December 20. A planet photographed at Flagstaff, 1913 June 10, may possibly be 132 Aethra.

VH was moving rapidly in declination when discovered. Its period is about four years.

Addendum.—The discovery at Simeis of planets VX, VY, VZ, WA, WB, WC, WD, WE, WF, WG, WH has just been announced. Details are reserved till next Report. This makes the total during the year sixty. Several of these will probably prove to be known planets.

A. C. D. C.

The Ninth Satellite of Jupiter.

On 1914 July 21, Mr. Seth B. Nicholson discovered this satellite at the Lick Observatory. It was estimated to be of the 19th magnitude, fully a magnitude fainter than VIII. Photographic positions were obtained on several days in July and August.

The following have been published :—

G.M.T.				R.A. of IX.			S. Decl. of IX.		
	d	h	m	h	m	s	°	'	''
1914 July	21	21	49.0	21	23	19.87	15	34	38
	24	22	6.2	21	22	3.07	15	41	55

The approximate values of IX - 7. and VIII - 7. at these times are—

	IX - 7.			VIII - 7.		
	m	s		m	s	
July 21	-6	41	+13.1	-7	44	+19.5
24	-6	36	+12.9	-7	46	+20.5

The period of IX is stated to be nearly three years, so that the solar perturbations will be still greater than those of VIII.

The inclination appears to be at least 30°; the eccentricity has not been published, but is presumably large. The motion is retrograde, like that of VIII.

A. C. D. C.

Comets in 1914.

At the beginning of the year Delavan's Comet (1913 *f*), which had been discovered on 1913 December 17, was close to the border of Eridanus and Cetus. It subsequently travelled through the S.E. corner of Aries, Taurus, Auriga, Lynx, Ursa Major, Canes Venatici, Boötes, Serpens, and at the end of the year was in Ophiuchus. It was invisible in the Sun's rays from April to the beginning of July, and was circumpolar at Greenwich in August, September, and the early part of October. Perihelion was passed on October 26 at a distance from the Sun of a little more than a unit, its closest approach to the earth—approximately $1\frac{1}{2}$ units—having occurred about a month earlier. Parabolic elements were computed by Van Biesbroeck (*A.N.*, 4711 and 4739); elliptical elements by R. Goudey (*A.N.*, 4717) and E. E. Kühne (*A.N.*, 4739); and, in addition to a parabolic, a hyperbolic orbit with $e=1.00163$ by S. B. Nicholson and Shane (*L.O.B.*, 255). As, however, the comet is likely to be within the reach of large telescopes for a long time, its orbit should be determined with great accuracy. In *A.N.*, 4728, Professor W. H. Pickering points out that the orbit bears some resemblance to that of 1860 III., and belongs to the type designated Q in *Harvard Annals*, 61, a type which in the last century furnished 57 per cent. of the comets of the two brightest grades.

Physical observations showed that, had the comet's perihelion distance been less, it would certainly have developed into a magnificent object, since under existing circumstances it was quite conspicuous to the naked eye and attracted considerable attention. It came within the range of naked-eye vision early in August, and at the time of its most favourable presentation (September and October) displayed a tail which, despite foreshortening, could be traced for about 5° . On photographs it was seen to be double, and to consist of a long, nearly straight tail of at least 10° length, and a broader, shorter, and curved tail, making an angle with the former of nearly 30° to the south (12° near the head). A plate taken at Greenwich with the 30-inch reflector on September 20 (*M.N.*, vol. lxxv. 1) shows considerable structure, and it appears that the long straight component which streamed out immediately behind the nucleus exhibited irregularities recalling Morehouse's Comet (1908 III.), whereas the shorter and curved tail bore some resemblance to that of 1910 I. Mr. Mellor says that the straight tail was characteristic of the tails usually found in small comets, while the southern one was characteristic of those found in large ones. The head of the comet was paraboloidal in form with a bright nucleus of about 6^m . The combined light was perhaps nearly equal to that of a 2^m star.

No observations are to hand of any other comet of 1913. Returns of the following periodical comets were expected in 1914, viz.:—*Encke's Comet*, *Tempel Swift*, which was observed as a faint

object at the return of 1908, after being missed at the two previous returns, *Giacobini's Comet* (1900 III.), which escaped detection in 1907, and *Metcalf's Comet* (1906 VI.). Of these, only *Encke's* appears to have been observed.

Comet 1914 a.—This Comet was discovered by Dr. Kritzing at Bothkamp on March 29 in the N. part of Scorpius. It traversed Ophiuchus, the S.E. corner of Hercules, the S. edge of Lyra, and Cygnus. Perihelion was passed on June 4 at a distance of a little more than $1\frac{1}{2}$ units from the Sun. When discovered it appeared as a round nebulousity of about 9.5^m . Mr. W. H. Stevenson observed it on April 18 to be elongated from *sp* to *nf*, with a well-marked condensation on the *nf* side of the centre. Although it brightened up to 8^m by May 2, according to Holetschek, it did not develop any features of special interest. It was observed at Bergedorf as late as December 14, when it was of 15^m .

Comet 1914 b.—This comet was discovered by M. Zlatinsky at Mitau, Russia, on May 15. It was then near η Persei and of 4^m . It had passed perihelion on May 8, and was travelling rapidly in a retrograde orbit between the Earth and the Sun. The elements of the orbit show a striking resemblance to those of Comets 1790 III. (Caroline Herschel) and 1911 *f* (Quénisset), and the three objects evidently belong to the same family. The path of the comet lay in Auriga, Gemini, Cancer, and Hydra. On May 23, M. J. Comas Sola photographed the comet with a tail at least 9° in length.

The comet's spectrum was photographed by Mr. Slipher at the Lowell Observatory (*Bulletin*, 63) with a one-prism spectrograph attached to the 24-inch refractor. There seems to be no continuous background, the dark places appearing to be merely gaps between emissions rather than absorption lines, so that the spectrum is limited to the comet's own light. A long slit was used, and, the nucleus being central on the slit, the length of the bright bands shows the distance to which the corresponding elements extended. It was found that they could be grouped into two classes, the carbon bands at $\lambda 5165$, $\lambda 4737$, and $\lambda 4381$, and the cyanogen bands at $\lambda 4216$ and $\lambda 3883$ being long; and the groups between $\lambda 4000$ and $\lambda 4100$, and between $\lambda 4300$ and 4350 (of which the identifications are uncertain), short, thus indicating that the luminous gases emitting them were confined to the neighbourhood of the nucleus.

Comet 1914 c was found by M. Neujmin, also the discoverer of 1913 *c*, at Simeis, Crimea, on June 24 in Scutum Sobieskii. It was a faint object of 12^m . The earlier elements published were considerably in error owing to the comet's distance, but the more accurate orbit computed by Messrs. Crawford and Shane (*L.O.B.*, 260) gave the date of perihelion as July 24, and the distance 3.743 units. This latter is surpassed only by the perihelion distance of the Comet of 1729, which was 4.051 units. Dr. Crommelin has pointed out that there is a general resemblance between the orbits of the two comets, and that they may be considered as belonging

to the same family. The apparent path traversed by Comet 1914 *c* was very much curved and lay in Scutum Sobieskii, Serpens, Ophiuchus, and Aquila. The Comet was observed at Bergedorf as late as December 22, when it was of 15^m.

Comet 1914 d.—This was a return of Encke's Comet, for which search ephemerides had been published by L. Matkiewitch and F. E. Seagrave, both giving December 5 as the date of perihelion passage. As Dr. Crommelin has remarked, when perihelion occurs about this time the comet is generally a fairly easy object, and on September 20 its detection at the Simeis Observatory, Crimea, was announced. It was afterwards found that it had been photographed by Professor Barnard on September 17. Though only of 14^m when first found, it brightened rapidly and reached 6^m on November 6. Mr. W. H. Steavenson then described it as "easy with 2-inch opera-glasses in spite of haze, well defined, small, bright, and compact, with a stellar nucleus of 8½^m." Amongst the photographs taken by Professor Barnard, one, of October 26, shows a slightly curved tail 2' wide; another, of October 29, shows the comet 18¾' in diameter and condensed, but not very strongly, on the *n.p.* side; and on a third, of November 28, a slender straight tail can be traced for more than a degree. Attempts had been made at Mount Wilson to photograph the comet at aphelion with the 60-inch reflector, and on a plate exposed for 3½ hours on 1913 September 1 there is an object close to the place indicated by Mr. Seagrave's ephemeris. There is some doubt, however, as to whether or not it is the comet.

Perihelion occurred, as predicted, on December 5, and the closest approach to the Earth (1.9 units) near the end of October. Its path lay in Aries, Perseus, Auriga, Ursa Major, Canes Venatici, Coma Berenices, Boötes, Virgo, Libra, and Scorpius, so that the comet was for a time in much the same region of the sky as Delavan's Comet had been previously.

Comet 1914 e.—An interesting feature in connection with this comet is its independent and almost simultaneous discovery by a number of observers. It was at first associated with the name of Dr. Lunt of the Cape Observatory, who discovered it on September 18. Later it was found that Mr. Westland of New Zealand had a few hours' priority; and the announcement was subsequently made that Mr. Leon Campbell at Arequipa had found it on the same day, but earlier still. The Greenwich mean times of the three independent discoveries in the order given are:—September 18.35, September 17.99, and September 17.74 respectively.

A further point of interest is its practically simultaneous discovery by Campbell with that of Encke's Comet (1914 *d*) photographically by Professor Barnard; the Greenwich mean times of Campbell's observation and Barnard's photograph being respectively September 17.74 and September 17.76. According to custom, therefore, Comet Campbell-Westland-Lunt should have been designated 1914 *d*, but in consequence of some uncertainty at

the time, the title was given to Encke's, and the earlier discovered comet is 1914 e.

Perihelion had been passed before discovery (viz. on August 5), at a distance from the Sun of a little less than $\frac{3}{4}$ of a unit. Very little information is to hand respecting its physical appearance. It was described as bright at discovery, and Mr. Bernard Thomas of Tasmania considered it equal to ϕ Eridani ($3^m.7$) on September 21 and 22, but by November 8 it was rated 9^m by Mr. Steavenson. Its apparent track was in Doradus, Reticulum, Horologium, Eridanus, Phoenix, Sculptor, Piscis Australis, Capricornus, Aquarius, and Pegasus.

The following are amongst the papers bearing on Cometary Astronomy published in 1914:—

In *A.N.*, 4717, there is an interesting paper by Herr Heinrich Svoboda, on the relationship of the Aquarid and Orionid Meteors with Halley's Comet. The connection of the η Aquarids of May and the Comet has already been well established, but in this paper the writer claims to prove that there is a similar connection between the Comet and the Orionid Meteors of October, the latter being encountered by the Earth when it makes its second nearest approach to the Comet's orbit.

In the same number (*A.N.*, 4717) M. S. Natanson gives a table of Comets together with Kleiber's orbital elements of meteoric streams based on radiant points in Denning's Catalogue of 1891, which may be associated with them. In this table also a relationship between the Orionids and Halley's Comet is suggested; while the very close resemblance of the elements of the Orionids and η Aquarids is again referred to by Mr. C. P. Olivier in his "126 Parabolic Orbits of Meteor Streams" in the publications of the Leander McCormick Observatory.

In *A.N.*, 4751, Herr W. Hassenstein claims to clear up the case of Flaugergues' Comet (1826 III.) and Biela's Comet (1826 I.) by showing that the alleged two objects are one and the same. The supposed separate existence of the former he traces to mistaken identifications in Flaugergues' comparison stars, and shows from his diagrams that the stars used can be identified with those along the track of Biela's Comet. The observation of March 29 alone cannot be thus explained, and might possibly refer to Comet 1826 II. (which seems unlikely), or to another and unknown object.

In *A.N.*, 4752, Professor W. H. Pickering gives reasons for supposing the two small comets 1858 III. (for which elliptical elements were found by Schulhof) and 1907 III. to be identical. Strömgren's elements for the latter were parabolic; but the comet was only under observation for 11 days. The Comet 1858 III. has not been recognised since its discovery, but on the assumption that the suggested identification is correct, the period in the interval must have been either 6.13 years for 8 revolutions or 7.01 years for 7. There is a gap in the periods of Jupiter's family between 6.00 years and 6.39 years, so that the latter appears more probable. In this case perihelion must have occurred about 1914

June 4, and a search ephemeris is given, based on the elements of 1907 with a period of 7.01 years.

Reference must also be made to a memoir by Prof. E. Strömgren entitled "Ueber den Ursprung der Kometen," *Mem. Acad. Sc., Copenhagen*, xi, 4, in which the writer proves that the hyperbolic character of a few orbits can be accounted for by planetary perturbations. Fresh evidence is thus forthcoming to establish the point that none of the comets in our catalogues have come from outside, but all must have originated within the solar system.

Elliptical elements have been found for Comet 1911 V. (Brooks) by Mr. Reynold K. Young (*A.N.*, 4714) and for Comet 1911 VI. (Quénisset) by Herr E. E. Kühne (*A.N.*, 4746).

The following definitive elements were published in 1914, both orbits being elliptical:—

Comet 1892 I. (Swift). By E. E. Kühne
(*A.N.*, 4713).

T = 1892 April 6.68945, Berlin M.T.

$$\left. \begin{aligned} \omega &= 24^\circ 31' 7'' \\ \Omega &= 240^\circ 54' 24'' \\ i &= 38^\circ 42' 20'' \end{aligned} \right\} 1892.0$$

$$q = 1.0268476$$

$$e = 0.99878$$

$$\text{Period} = 24484 \text{ years} \pm 372 \text{ years.}$$

Comet 1898 VIII. (Chase). By M. Wasnetzoff
(*A.N.*, 4712).

T = 1898 Sept. 20.16105, Berlin M.T.

$$\left. \begin{aligned} \omega &= 4^\circ 36' 49'' \\ \Omega &= 95^\circ 51' 51'' \\ i &= 22^\circ 30' 25'' \end{aligned} \right\} 1899.0$$

$$\log q = 0.358823$$

$$e = 0.999355$$

T. E. R. P.

The Total Solar Eclipse, 1914 August 20-21.

Extensive preparations were made for observations of the total eclipse of the Sun of 1914 August 20-21, the track of which extended across Norway and Sweden, and across Russia from Riga, through Minsk and Kiev, to the Crimea. In addition to numerous Swedish and Russian astronomers, there were four British official expeditions, and parties of observers from the Argentine, France, Germany, Italy, Spain, and the United States.

The outbreak of war at the beginning of August naturally caused serious disturbance of the plans of some of the intending observers. The British expedition to Kiev had to be abandoned, and the German astronomers who had gone to the Crimea were either ordered to leave the country or detained as prisoners of war. A party from Amherst College, under Professor Todd, succeeded in reaching Kiev, but were unable to get their instruments forwarded. Mr. R. C. Slater, who had sent his instruments to Riga in advance, was obliged to change his plans, and made his observations with improvised apparatus at Strömsund, in Sweden. The Rev. C. D. P. Davies and others who had intended going to Russia were unable to commence the journey, although in some cases instruments had already been dispatched.

Notwithstanding the distracting conditions under which the preparations had to be carried on, it is gratifying to record that interesting results were obtained by most of the observers who were fortunate enough to witness the eclipse in clear skies.

The expectation from meteorological records was that the most favourable localities would be in South Russia, but the actual conditions were almost completely the reverse. In Sweden the eclipse was seen under exceptionally good conditions, and at Riga also the sky was very clear. Further south, near Minsk, observations were only possible for the Greenwich party because of a fortunate gap in a cloudy sky. In the neighbourhood of Kiev it was too cloudy for observations, while in the Crimea the sky was generally cloudy, but with gaps which permitted observations at some of the places occupied. It is greatly to be regretted that among those who failed to secure observations were Professor Campbell's party from the Lick Observatory, which was stationed near Kiev, and Professor Newall's party from the Solar Physics Observatory, Cambridge, which occupied a site a few miles outside Theodosia, in the Crimea.

Successful photographs of the corona were obtained by, among others, Father Cortie at Hernösand, Mr. Slater at Strömsund, Dr. Backlund at Riga, and by Messrs. Jones and Davidson near Minsk. The corona is described generally as being of the expected "intermediate" type, in accordance with the phase of the Sun-spot period, which was on the rise from minimum to maximum.

Records of the flash spectrum do not appear to have been very numerous. There is promise of an important advance in our knowledge of the ultra-violet part of this spectrum, however, through the photographs taken by Messrs. Jones and Davidson with the Hills 4-prism quartz spectrograph, which show numerous lines extending as far as λ_{3100} . Also, some good plates of the red region of the spectrum were obtained by the Madrid astronomers, Messrs. Carrasco and Ascarza, who were stationed at Theodosia.

The most striking feature of the eclipse results yet reported was the unusual character of the spectrum of the corona. The familiar green line, λ_{5303} , is stated to have been absent, or extremely faint, while a previously unrecorded red line was very prominent. The wave-length of the latter is given as $6374\cdot5$ by Messrs. Bosler and Block, who formed the expedition from Meudon to Strömsund; and as $6373\cdot87$ by Carrasco and Ascarza. The substance represented by the new line, as in the case of the green line, has not yet been identified. Other well-known coronal lines besides that in the green were also missing.

Father Cortie reports several faint *groups* of lines in the coronal spectrum, two of which include the red and green lines at 6374 and 5303 ; he considers that these groups may possibly represent a band spectrum.

The following are references to reports on the expeditions and observations which have so far been published:—

- R. C. Slater, *Jour. Brit. Ast. Ass.*, xxv. 76.
 P. H. Hepburn, *Jour. Brit. Ast. Ass.*, xxv. 28.
 D. P. Todd, *The Observatory*, 1915 Jan., p. 53.
 W. W. Campbell, *Pub. Ast. Soc. Pacific*, No. 156, 1914
 December.
 J. Bosler and H. Block, *Comptes rendus*, clix. 766.
 P. Carrasco, *Comptes rendus*, clix. 740.
 A. L. Cortie, *M.N.*, lxxv. 105.
 A. Fowler, E. H. Hills, and W. E. Curtis, *M.N.*, lxxv. 117.
 H. S. Jones and C. R. Davidson, *M.N.*, lxxv. 125.
 H. F. Newall, *M.N.*, lxxv. 134. A. F.

Solar Activity in 1914.

Sun-spots.—The solar record for 1914 shows clearly that the revival has definitely begun. The first three months of the year were nearly as free from disturbances of the solar surface as the year 1913 had been, but a fine stream of spots appeared at the east limb of the Sun on March 30, and proved to be the first of ten important groups that were in evidence during the last three-quarters of the year. Of these six were in the northern hemisphere, viz. the groups seen March 30–April 11, April 26–May 3, August 13–26, September 10–22, November 7–15, and December 4–16. The four in the southern hemisphere were visible June 12–22, September 8–20, November 27–December 9, and November 28–December 4. All were in relatively high latitudes, and may therefore be presumed to be members of the new cycle of activity; spots in the equatorial zone, which might be supposed to be members of the old cycle, have not been observed.

Not only has this considerable number of important spot-groups been in evidence, but smaller and less stable groups have rarely been long absent, so that the mean daily spotted area for 1914 exceeded that for 1913 by more than twenty times. The faculæ, too, have shown a notable increase in number and brilliance, and their mean area has been fully five times as great as in 1913.

Other tokens of progress have been seen in the wide areas affected simultaneously by slight disturbances, of which a notable instance occurred on November 24, in the propagation of greater disturbances along considerable distances in longitude, as on December 3 when a "procession" of spot-groups was seen, some 36° in total length, and in the greater stability of some of the most important groups, as in that of August 13–26, which returned again in September and October, and thus had a life of fully two months. The same region where this great group appeared was also the scene of a sudden outbreak on November 7. Suddenness of appearance and violence of change have also been characteristic of several of the ten great groups referred to.

The movement towards recovery has made a sharp commence-

ment, but it is as yet too early to forecast the shape of the ascending branch of the curve. The present year will probably give a pretty distinct intimation as to whether there will be a sharp rise to a pronounced but short-lived maximum, or a slow increase towards a feeble and protracted one. The cycle just past was rather one of the latter character; the passage from minimum to minimum having occupied rather more than twelve years.

E. W. M.

The Prominences.—The Kodaikánal observations indicate a minimum of prominence activity in the year 1913; a notable increase both in numbers and areas has taken place during 1914.

If the two hemispheres of the Sun are considered separately, the mean areas for the northern hemisphere have their smallest values during the years 1912 and 1913, and remain sensibly constant during those years. In the south there is a steady diminution of prominence area during 1911 and 1912, reaching a minimum value in the second half of 1913. The mean frequencies give essentially the same results, and the minimum frequency and minimum area for the whole Sun is shown in the latter half of the year 1913.

The mean areas obtained from the Kodaikánal photographic and visual records are as follows:—

	North.	South.	Total.
1913 January to June	1'23	1'19	2'42
„ July to December	0'91	1'01	1'92
1914 January to June	1'44	1'49	2'93
„ July to December	1'59	1'75	3'34

These figures express the mean areas per diem in square minutes of arc. The mean frequencies give similar results, but they are less informing as to the changes of activity in the Sun, and are indeed misleading when compared with results obtained from other observatories where only the larger prominences are recorded. At Kodaikánal it is the rule to record everything shown on the photographs, and the average number of separate prominences shown on the plates at a time of minimum sun-spots is as great as fifteen, whilst at maximum the number does not exceed twenty-two; the change in frequency with the sunspot cycle is therefore not very marked in this series of records.

It is of interest to note that the time of minimum prominence area for each hemisphere coincides with the sunspot minimum in the same hemisphere according to the Kodaikánal numeration of spots. The great majority of prominences are, however, not directly associated with spots, the zones of greatest activity being in higher latitudes than the spot zones, and the prominences found in the spot latitudes usually occur in the areas between the spot disturbances.

The class of prominence directly connected with spots is dis-

tinct, and forms a very small proportion of the whole; these naturally follow the sunspot numbers very closely.

The distribution of the prominences in latitude has been much the same throughout the two years under review, there being well-marked zones of activity in each hemisphere between the parallels 40° and 50° , and a minimum of activity from 60° to the poles. The increase in 1914 affects all latitudes from the equator to 60° .

The proportion of prominences found on the eastern side of the Sun's axis to the whole number was 50.5 per cent. during 1913; this shows a much smaller eastern excess than has been found for each of the years 1905 to 1912 inclusive, the average eastern proportion for those years being 52.8 per cent. The year 1913 would seem, in fact, to indicate a discontinuity in the long series of years showing this remarkable feature, for in 1914 the number of eastern prominences was 49.9 per cent. of the whole.

No very large eruptive prominences were recorded at Kodaikanal in 1913 or 1914, and of metallic prominences only five were observed in 1913 whilst seventeen were recorded in 1914. Prominences showing displaced lines have been rather frequently recorded during 1914, the greatest displacement observed in the C line being 5 A towards the red in a prominence situated at latitude $+82^{\circ}$ E. on August 26.

J. E.

Solar Research in 1914.

Periodicities.—An interesting photo-mechanical method of investigating periodicities has been applied to the sun-spot curve by A. E. Douglas (*Ap. J.*, xl. 326). The chief period was found to be less predominant than was expected, and to range from 11 to 11.8 years. Other periods are also indicated by this "photographic periodogram."

J. B. Dale (*M.N.*, lxxiv. 628, 664) has described a new method of discovering the fundamental periods of a periodic function. In another paper (*M.N.*, lxxiv. 664) the method is applied to fluctuations in the epochs of sun-spot maxima and minima. The value derived for the main period is 11.4 years during the last century and a half, but earlier observations are not represented correctly by the formulæ, and it may be that the period is slowly lengthening. Other periods are suggested, but accidental errors of the data are probably so great that a formula for purposes of prediction cannot be deduced with confidence.

A. Schuster (*Proc. Roy. Soc.*, A, xc. 349) explains that while Newcomb's method of determining periodicities does not give any more than can be obtained from Fourier's analysis, it has the advantage of great simplicity in numerical work; it is only applicable, however, in certain special cases.

Royds (*Kod. Obs. Bull.*, No. xxxiv.) has made a periodogram

analysis of prominence frequencies, and has found, in agreement with Ricco and others, that the maxima of the predominant 11-year period fall about a year later than those of spots.

A further periodogram analysis made by Royds and Sitamara (*Kod. Obs. Bull.*, No. xxxv.) indicates the improbability of any of the planets, including the Earth, having any influence on the relative numbers of prominences on the eastern and western limbs of the Sun. It seems probable that the observed excess on the eastern limb must in some way be due to the Sun's rotation.

R. A. Sampson (*M.N.*, lxxv. 82) criticises adversely the explanation of the 11-year period of spots put forward by Turner last year. Turner's reply is given in *M.N.*, lxxv. 138.

Solar Radiation and Temperature.—G. A. Shook (*Ap. J.*, xxxix. 277) has made a new determination of the Sun's temperature by photometric comparisons of the Sun's disc with a filament lamp. The resulting "temperature" at the centre of the disc is 7500° for red, 5990° for green, and 5230° for blue light; the different values indicate that the Sun does not radiate as a black body, and are consistent with the view that the radiation comes mainly from a shallow layer and that the radiations of shorter wave-lengths are subjected to greater scattering than those of longer wave-lengths.

Observations with an Ångström pyrheliometer were made on Mount Whitney on seven clear days in the summer of 1913 by A. K. Ångström and E. H. Kennard (*Ap. J.*, xxxix. 350). The observations are stated to give no support to a value of the solar constant exceeding 2 cal./cm.² min.

F. W. Very (*Am. Jour. Sc.*, xxxvi. 609), on the other hand, maintains his view that the solar constant cannot be less than 3, and may be as much as 4 cal./cm.² min. He holds that a large fraction of the solar radiation disappears by absorption in the so-called isothermal layer.

Abbot and Fowle (*Rep. Astrophys. Obs. Washington*, 1914) have continued their work in several directions. Substantial progress has been made in experimental work on the absorption of water vapour. Pyrheliometer readings at heights up to 14 km. have been obtained by the use of free balloons, and these are stated to confirm the Smithsonian value of the solar constant (193). A tower telescope 50 feet in height has been erected at the Mount Wilson station for work on the distribution of radiation along the solar diameter; by its means the variability of the Sun has been independently confirmed, for it appears that changes in the distribution of radiation over the disc synchronise with the changes in the total radiation.

J. N. Pring (*Proc. Roy. Soc.*, A, xc. 204) has made estimations, by a new method, of the amount of ozone in the atmosphere, a knowledge of which may be of considerable importance in connection with estimates of the solar radiation. The average amount in England at high altitudes is 2.5×10^{-6} in one volume of air, and no large increase occurs between 5 km. and 20 km. It

is concluded that ozone must be regarded as a contributing factor to the blue colour of the sky.

The results of 13 years' measurements of solar radiation made by L. Gorczynski at Warsaw are summarised by E. Gold (*Nature*, xciii. 362). The marked reduction in intensity about the end of 1912, possibly due to the eruption of Mount Katmai, is clearly shown.

A. Verronet (*C.R.*, 1914 June 8) has reviewed the various hypotheses as to the maintenance of the Sun's heat, and concludes that the Helmholtz contraction theory is in best accord with facts.

A. S. E. Ackermann (*Nature*, xciii. 366) gives an account of progress made in the use of solar radiation as a source of mechanical energy.

Solar Rotation.—F. Schlesinger (*Pub. Allegh. Obs.*, iii., No. 13) has published an interesting account of the Porter spectrograph, and of determinations of the solar rotation which have been made by its use. The part of the spectrum included in the observations was that between $\lambda 4059$ and $\lambda 4126$, in addition to the region $\lambda 4220$ to $\lambda 4277$ which is intended to be common to all the observers co-operating in the scheme of the Solar Union. The range of heliographic latitude covered by the photographs was 0° – $64^{\circ}8$, and the resulting diurnal angular motion is finally expressed by the equation $\xi = 14^{\circ}17' - 3^{\circ}4' \sin^2 \phi$.

The probable error of a plate is 0.030 km./sec., which is much greater than would be expected from internal evidence. It is difficult to account for the lack of accordance between plates taken on different days, except on the hypothesis of local and temporary drifts in the reversing layer. The value of the equatorial velocity deduced from the observations is 2.00 km./sec., as compared with Dunér's 2.09 , Adams' 2.05 , Storey and Wilson's 2.08 , and Evershed's 1.94 . Dr. Schlesinger is strongly of opinion that the diversity of these results is due to systematic errors at the measuring machine, and, more especially, at the telescope. No certain indications of differences in displacements for different elements were found.

Displacements of Solar Lines.—An interesting series of investigations of the displacements of lines at the centre and limb of the Sun have been made at Kodaikánal by Mr. Evershed, Dr. Royds, and other members of the Observatory staff (*Kod. Bull.*, Nos. 36, 39, 40, 44, and *Observatory*, xxxvii. 124). The observations include comparison spectra of the centre and limb of the Sun, and direct comparisons of each with the iron arc, together with laboratory studies of the varying wave-lengths and characters of a number of lines of several elements in different parts of the arc, and in arcs of different lengths.

The outcome of the numerous investigations is to suggest that the general displacement to the red of lines at the centre of the Sun, as compared with the arc, is more probably due to motion than to pressure. A mass of evidence has, in fact, led the Kodaikánal observers to conclude that the pressure in the reversing

layer cannot be as much as one atmosphere ($\frac{3}{4}$ an atmos. is their estimate), and that the shifts in question can be simply accounted for by a descending motion of the absorbing vapours, which is greatest in the higher levels and is retarded in the lower and denser regions. The results further suggest that the general displacements towards the red at the limb of the Sun, as compared with the centre, are also due to motion, the velocity in the case of iron being about 1 km./sec. A movement of recession from the earth is thus indicated as existing over the entire disc of the Sun, leading to the startling suggestion that the Earth exerts a repulsive action on the solar gases. It is possible, however, that some cause of line-shifts other than pressure or motion remains to be discovered.

The Chromosphere.—S. A. Mitchell (*Ap. J.*, xxxix. 166) has further discussed his eclipse spectra of 1905 with special reference to the depths of the reversing layer and the relative intensities of the lines of different elements. On the average a line of intensity 1 in the chromosphere has an approximate height of 350 km., and there is an increase of about 80 km. for each unit increase of intensity. St. John (*Ap. J.*, xl. 356) has also discussed Mitchell's eclipse spectra in connection with the Evershed radial velocities in spots, as observed at Mount Wilson, and finds support for his view that the Fraunhofer lines originate at depths which increase regularly with the decreased intensity of the solar lines. It is concluded that the Evershed effect provides a means of sounding the solar atmosphere with a high degree of precision. Julius, however (*Ap. J.*, xl. 1), denies that St. John's observations of the radial motions in spots are decisive in favour of the view that the Doppler effect is the principal cause of the observed displacements. Julius does not regard the observations as entirely in favour of an explanation based upon anomalous dispersion, but claims that this interpretation has more features to recommend it than that depending upon radial motions.

Researches in the Laboratory.—A. S. King (*Ap. J.*, xl. 205) has given a description of a vertical adaptation of the Rowland mounting for a concave grating which has been erected in the Pasadena laboratory. The greater part of the instrument is in a pit below the floor, and the temperature control is very satisfactory.

Dr. King (*Ap. J.*, xxxix. 139) has also made a valuable study of the variation with temperature of the electric furnace spectrum of titanium in the region 3888 to 7364. The data are likely to be of use in the discussion of solar and stellar spectra, and incidentally the observations support the view that the band spectrum characteristic of third-type stars is due to oxide of titanium and not to titanium alone.

Another important research by King (*Ap. J.*, 212) refers to the effects of a hydrogen atmosphere in connection with the appearance of enhanced lines. Such an effect is observed in experiments on the arc, and has several times been suggested as a possible cause of the special development of enhanced lines in the

upper chromosphere. The electric furnace is especially adapted for such an investigation, and the experiments have failed to show any effect of hydrogen in strengthening enhanced lines, which appear with equal ease at low pressures whether the residual gas is hydrogen or air. The great relative strength of enhanced lines in the upper chromosphere would thus seem to follow from the rarefied conditions at these high levels, which allows a high speed to be retained by electrons expelled from the heated matter below; the conditions of presumably reduced temperature and pressure in the upper chromosphere are unfavourable for the arc lines, which are relatively weak. The relative strength of arc and enhanced lines thus remains as a valuable criterion of temperature, either in Sun or stars, since the electronic speeds would depend upon the temperature of the photosphere.

Miscellaneous.—A. L. Cortie (*M.N.*, lxxiv. 670) has drawn attention to an area of long-continued solar disturbance, and magnetic storms associated with it. The disturbed area persisted as such for the two years 1909-10, the maximum being marked by two large spot groups. The associated flocculi and prominences were extensive and widely distributed, and the greater phases were accompanied by a series of well-marked magnetic storms. The discussion suggests a divergent action from the sun-spot centres, in confirmation of previous results.

The areas of calcium flocculi in spectroheliograms of 1906-8, as measured and reduced at the Solar Physics Observatory, South Kensington, are given in one of the final publications of this institution (H.M. Stationery Office, 1914).

Volume iv. of the *Transactions of the International Union for Co-operation in Solar Research* was published during the year. It gives a detailed account of the proceedings at the Bonn meeting in 1913, and includes several valuable communications, among which is an important paper by Carl Störmer on the mathematical theory of solar vortices.

A. F.

Double Stars.

The abbreviations used are—

M.N.: *Monthly Notices, Royal Astronomical Society.*

A.N.: *Astronomische Nachrichten.*

L.O.B.: *Lick Observatory Bulletin.*

B.A.A.: *Journal of the British Astronomical Association.*

New Double Stars and Measures of known Pairs.—No. 29 of the *Journal Astronomique*, issued from the Observatory of the University of Lille, 1914 June 12, contains measures of 43 pairs previously discovered by M. Jonckheere, and measures of Sirius in 1914. Also measures of 33 new pairs (J 1035-J 1067) discovered

by him in his systematic search (see details, *B.A.A.*, 1914 Nov.). These are all under 3" separation.

The Transvaal Circular, No. 14, contains a set of measures of over 540 southern double stars, made with the 9-inch Grubb refractor in 1912 and 1913. The measures were, in general, made by Messrs. Innes and Van der Spuy. Attention was paid to colours. There are short notes to many pairs and special notes to a few such as α Fornacis, Innes 83, Innes 221, and A Ophiuchi.

Mr. Innes also contributes to *M.N.*, June, a note on the magnitude of η Argûs, and announces the discovery of a faint companion of 10.5 mag. in position 74° at a distance of 1".

The Rev. T. E. R. Phillips publishes, in *M.N.*, March, measures of 67 Struve pairs made by him in 1913 with the 8-inch refractor lent by the Society. A few were made with the $12\frac{1}{4}$ -inch reflector. The pairs include γ Andromedæ and ζ Boötis.

In *M.N.*, April, Mr. W. S. Franks publishes measures of 360 wide pairs made with the $6\frac{1}{8}$ -inch Cooke refractor at Mr. F. J. Hanbury's observatory, Brockhurst. The 360 stars embrace (1) all the stars in Otto Struve's Catalogue of 256 doubles between 32" and 2' separation; (2) the 60 objects in M. Struve's Appendix I.; (3) a selection of other Σ wide pairs; (4) miscellaneous pairs.

The value of these measures is enhanced by the completeness of the redetermination of the relative positions of all the wide pairs in O Σ and Σ catalogues.

Mr. Franks, in *M.N.*, May, also gives measures and a note on the group O Σ 137.

The Rev. T. E. Espin, *M.N.*, 1914 Jan., gives his tenth series of measures of miscellaneous stars. There are 20 under 5" and 105 over 5" separation. In the same number are Mr. Espin's new doubles (1192 to 1293), of which 52 are under 5" and 50 over 5" separation.

Dr. W. J. Hussey's first issue, *Observatorio Astronomico de la Universidad Nacional de La Plata*, tomo i., contains a list with measures of new double stars found by him with the 17-inch refractor. This is really Dr. Hussey's 13th Catalogue, and the stars are numbered Hu 1339 to Hu 1550. There are 63 stars under 1" separation. For a review of the whole volume see *Observatory*, No. 481.

In *B.A.A.*, 1914 Jan., are measures of 20 Struve pairs made with a 5-inch Cooke in 1913 by Mr. R. C. Slater.

L.O.B., 251, 263, 264, contain respectively Dr. Aitken's lists Nos. 21, 22, 23 of new double stars. These additions bring up Professor Aitken's numbers to 2900. There are 31 pairs of separation 0".25 or under; 61 pairs with separation between 0".25 and 0".5; and 208 between 0".5 and 5".0 separation. These are practically typical of the whole 2900.

Doppelstern Messungen angestellt am Faden Mikrometer des 10 $\frac{1}{2}$ zölliger Refractors von 1910 Aug. bis 1913 Juni, von J. Voûte an der Leidener Sternwarte. In this volume are measures of 263 Struve, 64 Otto Struve, 17 β , and 26 miscellaneous stars in the

zone from the equator to $+56^{\circ}$ Dec. The focal length of the refractor is 14.8 to 1. Distances under $0''.6$ are estimations. The measures of many of the principal pairs are compared with orbits. Sirius was measured each year, and among others are, Σ 3121, ζ Boötis, Σ 1639, O Σ 38, and O Σ 208.

Observations d'étoiles doubles faites à l'équatorial de 38 centimètres d'ouverture de 1907 à 1912 par G. Van Biesbroeck, Bruxelles, 1914. This is M. Biesbroeck's third series; the first set were made with the same instrument in 1903-4, the second set at Heidelberg in 1905. The stars are selected first as showing orbital motion, and out of the 180 Struve pairs there are 63 with separation under $0''.5$. But the feature is that M. Biesbroeck has devoted much time to the identification and measurement of some 300 Herschel stars.

A.N., 4715. Measures of 104 pairs by Dr. Doberck. There are 25 under $2''$ separation. A second set of 151 stars is in A.N., 4745; of these $58''$ are under $2''$ separation.

A.N., 4727. A new double star B.D. $+41^{\circ}2210$, mag. 8.7, separation $1''.5$, by Karl Bohlin.

A.N., 4735. Measures of 40 pairs by C. Luplau-Janssen and Buch-Andersen. These are mostly Struve wide pairs.

A.N., 4744. Measures of 39 Struve pairs by R. S. Dugan with the 23-inch Princeton refractor. There are also measures of 15 Struve and 21 Otto Struve wide pairs by F. Pavel with the 8-inch refractor at Breslau.

A.N., 4747. Measures of 32 Struve pairs by Ruben Andersen with the 14-inch refractor of the University Observatory, Copenhagen.

In No. 156 of the *Astronomical Society of the Pacific* there are measures of the binary Aitken 570.

The *Bulletin Astronomique* for June contains measures of 63 pairs, mostly J. Herschel, made with the $8\frac{3}{4}$ -inch refractor at Santiago by M. Grandson during the years 1870 to 1914.

There are three published catalogues of double stars derived from astrographic plates, viz.:—

Perth, S. Australia, zone -40° , by R. W. Wrigley.*

Perth, S. Australia, zone -31° , -32° , by C. Nossiter.†

Potsdam, Germany, zone $+31^{\circ}$ to $+40^{\circ}$, by J. Scheiner.‡

Publication of the Lick Observatory, vol. xii., *Measures of Double Stars*, by R. G. Aitken. This is a volume of 180 pages containing all Professor Aitken's measures of known pairs since 1895. There are 552 β , 226 Σ , 113 Ho, 67 O Σ , and 243 miscellaneous pairs. Professor Aitken has paid particular attention to binary stars and pairs where the separation is small, $0''.2$ or less. In consequence there are numerous series of measures of such

* M.N., 1911 Nov.

† The Perth Observatory Bulletin, No. 1.

‡ Publicationen des astrophysikalischen Observatoriums zu Potsdam, zwanzigsten Band.

pairs extending, in general, over 16 years. It is doubtful if so valuable a set of measures could be obtained elsewhere. In addition to the measures are investigations of systematic error, calculations of orbits, and general remarks. In connection with the orbits there are 6 under a twenty years' period, viz.: δ Equulei 5.7, $\text{Ho } 212$, 6.9, κ Pegasi 11.4, Aitken 88, 12.1, ϵ Hydræ 15.3, and β 883, 16.6, and no doubt Professor Aitken's pairs will yield others. Both Professor Aitken and the Lick Observatory are to be congratulated on the publication of such a unique volume.

Computational and Theoretical Papers.—In No. 29 of the *Journal Astronomique* (Lille) M. Jonckheere gives a third series of useful ephemerides of binary stars. The present stars are O Σ 234, O Σ 235, O Σ 269, γ Virginis, γ Centauri, Σ 1728, Σ 1768.

A.N., 4710. A note by Dr. Doberck "On the effect of definition on micrometric measures."

In the 1914 December issue of the *Astronomical Society of the Pacific*, Professor Campbell, on pp. 250-1, gives a review of the double-star work at Lick.

A.N., 4715. Dr. R. Furuhielm, of the Helsingfors Observatory, has a note on "Capella," and announces that from his photographic plates there exists a faint companion of 10.6 mag in position-angle 141° and at a distance of 12', which has the same proper motion as Capella.

Mr. Lewis has continued his notes on various points in connection with double-star astronomy. Thus *Observatory*, No. 474, contains "Magnitudes"; No. 479, "Classes of double-stars observable with various apertures"; No. 481, "Telescopes." T. L.

Giant and Dwarf Stars.

While many astrophysicists considered that the evolutionary order of the stars was represented by a progression from Nebulæ through the blue stars to the red stars, Sir Norman Lockyer maintained the view that, starting from a collection of meteoric matter, the development proceeded through the cooler red stars up to the hotter blue ones and then downwards again to the red stars. The same view on other grounds has recently been advocated by Professor H. N. Russell.* The foundation of Russell's work is found in the discovery made independently by Professor Herzprung and himself that red stars fall into two distinct groups, one of very great and the other of very small luminosity. For stars of type K5 to M the stars of great luminosity or "giants" have a mean absolute magnitude not far from $-0^m.3$ and range about $1\frac{1}{2}$ mag-

* An account of Russell's work was given in a lecture to a joint meeting of the Astronomical and Astrophysical Society and Section A of the American Association for the Advancement of Science, and is reported in *Nature*, vol. xciii. pp. 227, 252, 281.

nitudes on either side of this, and the stars of small luminosity have a similar range about $+8^m.9$. For K₀ the "giants" range about $0^m.2$ and the "dwarfs" about $6^m.4$. For the G stars the "giants" have a mean absolute magnitude of $-0^m.2$ and the "dwarfs" of $5^m.0$. For type F the groups overlap considerably and in type A are completely mixed, as the two groups are much closer together—the "giants" remaining at about $0^m.0$ and the "dwarfs" about $3^m.3$ for type F₃ and $1^m.5$ for type A₅. The B stars are all "giants," and their absolute magnitude is taken as $-1^m.4$. (The Sun is taken by Russell as of absolute magnitude $4^m.7$: this gives a datum for comparing the luminosities of these stars with that of the Sun.)

These results are in the main obtained by calculating the luminosities of stars whose parallaxes have been determined. They are supplemented from the parallaxes of the stars in the Taurus, Ursa Major, and Scorpius clusters, and by the mean parallaxes obtained from the parallactic motion or mean peculiar motions found in researches by Kapteyn, Campbell, and Boss. The separation of the red stars into these two classes seems to be well established. For example, Professor Eddington (*Stellar Movements and the Structure of the Universe*) gives eight stars of type Ma whose parallaxes are determined with considerable accuracy. Their luminosities are

$0^m.19$, $0^m.11$, $0^m.10$, $0^m.09$, $0^m.08$, $0^m.42$, $0^m.13$, $0^m.13$,

and their absolute magnitudes range from about $8^m.2$ to $10^m.1$. These stars are all "dwarfs."

On the other hand, if the K₅ – M stars be picked out from any catalogue giving their proper motions, it will be found that these are uniformly small—with only solitary exceptions,—that the stars are therefore distant and of great luminosity, and that the mean absolute magnitude is approximately $0^m.0$ to $-0^m.5$. This appears to be true for stars of all magnitudes brighter than the B.D. limit.

The next stage of the inquiry consists in the interpretation of these great differences in luminosity. The surface-brightnesses for stars of the same type are hardly likely to be very different. Examination of spectroscopic and visual binaries leads to the conclusion that there is no great range in the masses of stars, though the B stars have been shown by Ludendorff to be in the mean three times as massive as stars of other types. The researches of Russell, Shapley, and others on variable stars show that there are very great differences of density among the stars. The differences between the "giants" and "dwarfs" is attributed to this cause. Although the available evidence is somewhat meagre, this conclusion appears to be established. It would certainly seem difficult to suppose that the differences between "giants" and "dwarfs" are to be attributed to differences of mass.

The densities of the "giant" M stars are extremely small. As the stars condense the temperature rises and the increase of surface-brightness more or less compensates for the loss of surface, and thus the stars remain of about the same luminosity till the A stage is

reached. Only the more massive stars reach the high temperature of the B stage. Further condensation from the A stage is accompanied by falling temperature and diminution of surface-brightness, and consequently the luminosities of the "dwarf" stars of successive types diminish very rapidly. The Wolf-Rayet stars and the planetary nebulae are presumably extreme cases which occur in the middle of this scheme of development.

The observational facts establish the existence of two distinct classes of red stars, and form a substantial basis for this hypothesis. The question arises how it agrees with the discoveries recently made of the progressive increase in the distance of the components of binary stars as the type of spectrum changes, and with the progressive increase in the velocities of stars between the types B and M. Both of these curious relations have been held as confirmatory of the order of evolution from B to M. In reply to Eddington, Russell remarks that, assuming binaries to be formed by fission, their existence among B stars implies that these stars are somewhat advanced in stage of development. He also draws attention to an important point which should not be overlooked, that tidal friction can only increase the separation of double stars whose components are fairly equal to a very restricted extent. As regards the greater linear velocities of red stars, it should be noticed that though the information derived from researches on line of sight velocities or proper motions relates almost wholly to "giant" stars, there is evidence that the "dwarf" red stars also have large peculiar velocities. It can hardly be supposed that the velocities of red stars diminish as they become bluer and increase again as they become red. On the other hand, too much weight should not be given to a statistical relation whose physical cause is not understood.

There are few facts in stellar astronomy which will not have some bearing on such a far-reaching hypothesis. One which occurs to the writer is that the number of "dwarf" red stars in a given volume of space is very much larger than the number of "giants." A great merit of the hypothesis is its suggestiveness of further lines of research and observation. Already Herzprung has detected slight differences in the spectra—a sharpness of the lines indicated by Miss Maury in the Harvard classification by the letter *c*—which appear to be characteristic of the "giant" stars. A spectroscopic means of discriminating the two classes of stars should be of great value for comparison with the results obtainable by means of measured parallaxes or the estimates of distance derived from proper motion. It seems natural to expect that differences in the spectra will be found between stars of the same temperature and widely different densities, and it is perhaps to detailed astrophysical research that we must look for a decisive answer as to the course of stellar development.

F. W. D.

Stellar Distribution and Drift.

Stellar Parallaxes.—In *Ast. Nach.* 4709 a series of 35 parallaxes, determined from photographs taken with the 40-inch refractor at Yerkes, is published by F. Slocum and S. A. Mitchell. Of these, 14 had already been given in *Astroph. Journ.*, xxxviii. p. 1. In *Ast. Nach.* 4760 a further list is given by Slocum. The parallaxes of the three components of the triple system Lal. 6888-9 have been measured, and found to be inappreciable, although the annual p.m. is $1''.4$. The new parallaxes $>''\cdot 075$, in addition to those in *Astroph. Journ.*, xxxviii., are O.A.(N.), 4961, p.m. $0''.48$, parallax $''\cdot 094$, and 85 Pegasi, p.m. $1''.30$, parallax $''\cdot 084$. Measures have been made for the 4 stars in the Trapezium in Orion, each giving negative parallaxes.

A number of American observatories (Yerkes, Swarthmore, Dearborn, McCormick, Allegheny, and later others) are devoting much time to determinations of stellar parallax. A committee of the American Astronomical Society, with F. Schlesinger as chairman, has just been formed to organise a scheme of co-operation between these and other observatories engaged in parallax work, and to obviate unconscious duplication. The Greenwich Observatory and some other European observatories are also engaged in parallax determinations, and a high degree of accuracy is being attained in all these results.

The programme of parallax determinations now being carried out at Greenwich includes selected stars in the region covered by the Greenwich Astrographic Catalogue, and the first results were given in the Astronomer Royal's report to the Board of Visitors.

J. C. Kapteyn (*Astroph. Journ.* 40, p. 43) has made a first attempt to find the parallaxes of all the helium stars brighter than $6^m\cdot 0$, lying between $\pm 30^\circ$ galactic latitude and $216^\circ - 360^\circ$ galactic longitude. Using the fact that the p.m.'s of these stars show a general parallelism, and possibly form a group, evidence of which is also obtained from the radial velocities, he has been able to deduce hypothetical parallaxes for the individual stars, and also to obtain the luminosity curve.

Owing to the very small random velocities of these stars and the marked streaming motion shown, these determinations are doubtless very close to the true values, and an important addition to our knowledge of these stars. Kapteyn also attempted to extend the same method to stars of later type, but owing to their large accidental velocities it is doubtful whether the method is of much value for these stars.

In *Ast. Nach.* 4754 O. W. Walkey has given a summary of measured parallaxes, the stars being divided into groups according to their type and summarised as regards their distances, luminosities, and cross p.m.'s.

Radial Velocities.—The programme of radial velocity determinations at the Mount Wilson Observatory has been limited to

stars brighter than $5^m.5$ on the visual scale, for which parallax determinations are also available. The determination of the radial velocity completes our knowledge of the fundamental constants of these stars. In *Astroph. Journ.* 39, May 1914, W. S. Adams and A. Kohlschütter give the radial velocities found for 100 of these stars—the spectral type and cross velocity as deduced from the parallax and p.m. being also given. Of these stars 7 have absolute radial velocities greater than 100 km. per sec. (2 F, 3 G, 2 Ap stars). Küstner (*Ast. Nach.* 4750) has published a list of 227 additional radial velocity determinations (stars of types F to M), made at Bonn, together with the wave-length values upon which the determinations are based. The systematic differences between the radial-velocity results obtained at different observatories have been discussed by H. Ludendorff (*Ast. Nach.* 4705) and S. Albrecht (*Astroph. Journ.* 40, Dec. 1914). Albrecht concludes that the differences are largely due to differences between the assumed wave-lengths upon which the derived values rest.

O. J. Lee (*Astroph. Journ.* 39, Jan. 1914) gives measures of 28 variable radial velocities made at Yerkes; 18 of these stars were previously known to be spectroscopic binaries. The remaining 10 are new.

In *L. O. Bulletin*, 257, J. H. Moore and R. E. Wilson give measures of 22 stars with variable radial velocities. Moore also announces the discovery of two stars with the large velocities of +184.8 and +184.4 km. per sec.

The Star Streams.—The results of a statistical study of more than 1400 radial velocities by Charlier's method are given by K. W. Gyllenberg in an important communication "On the 3-axial Distribution of the Velocities of the Stars" (*Lund Obs. Meddelande*, 59). Assuming Schwarzschild's ellipsoidal representation, the positions of the axes and their lengths, or equivalent velocities, are determined for the stars as a whole, and a similar determination is based upon the proper motions. The stars are then split up according to magnitudes, but there is no evidence of a dependence of the apex upon magnitude. Dividing according to spectral type, a considerable dependence is found. Gyllenberg divides the stars into three groups, and derives by two independent solutions for each group the position of the apex and the value of the solar motion, together with the lengths and positions of the axes of Schwarzschild's ellipsoid. The second solution allows for a possibility of a systematic error in the determinations (Campbell's K term). The results of this solution for the apices are:

Spectral Types.	Apex.	Solar Motion.	K
B and A	$273^{\circ}.4 + 24^{\circ}.3$	19.7 km.	+1.46 km.
F and G	$270^{\circ}.2 + 23^{\circ}.2$	17.5 „	+0.42 „
K and M	$271^{\circ}.4 + 31^{\circ}.3$	19.9 „	+3.98 „

For the third group the ellipsoid is found to be almost circular.

B. Boss in *Astron. Journ.* 668 has also discussed the dependence of the solar motions derived from proper motions and from radial velocities upon the magnitude, type, and galactic latitude of the stars used. He finds that there is no evidence of a shift in the galactic longitude of the apex of the solar motion with change of the mean magnitude of the stars employed in its determination, but that there may possibly be a slight shift in galactic latitude. He found, however, that the position of the apex was dependent upon the spectral type of the stars used, there being a difference of 12° in the galactic longitudes of the apex as derived from early and late stars, though there is no change in latitude. The evidence for this—derived from the proper motions—is supported by the treatment of the radial velocities. There is also a difference of 6 kms. in the values of the solar velocity derived from the two classes of stars. Boss considers these results as possibly due to a relative drift between the early and late type stars. He finds also a systematic difference between the apices as derived by the two methods, except for B stars, and suggests that either the small real velocities of these stars fit them for solar motion determinations, or that there is a drift amongst them which unfits them.

In *Astron. Journ.* 669 Boss gives further evidence of the reality of the antapex group (*Astron. Journ.* 635-6) obtained from radial velocity determinations for some of the stars. The group velocity comes out at $+21$ km. per sec., relative to the Sun, indicating that the stars of this group are practically at rest in space.

From an examination of the residuals of the proper motions of the stars in the Taurus cluster, perpendicular to the lines joining the stars to the convergent, J. O'Connor (*Astron. Journ.* 669) concludes that, although the residuals are considerably less than their probable errors, their signs are such as to suggest that the stars, besides moving in parallel lines, are also revolving about a common centre. The minuteness of the quantities involved renders this result very uncertain.

Spectral Type.—H. N. Russell has given a summary of the arguments in favour of his theory of Giant and Dwarf stars in *The Observatory*, xxxvii. p. 165; a fuller account is also given in *Nature*, xciii. pp. 227, 252, 281.

H. S. Jones (*M.N., R.A.S.*, lxxiv. p. 168) has discussed the proper motions of the brighter stars within 17° of the Pole in relation to their spectral type. He shows that the average parallax reaches a maximum for the solar type stars, but that the average radial velocity increases progressively with type, in accord with Campbell's result. The evidence of streaming was strongest for the solar type stars. Assuming Schwarzschild's representation, the ratio of the axes of the ellipsoid for stars of different types was found.

F. W. Dyson (*M.N., R.A.S.*, lxxiv. p. 733) has discussed the proper motions of the stars in Carrington's Circumpolar Catalogue in relation to their spectral types. These stars are on the average

faint, and their colour indices have been used as a basis of classification. The surprising result was the great average distance and absolute luminosity found for the reddest stars, whereas the red stars of measured parallaxes are near and of low intrinsic luminosity. The bearing of this result on Russell's theory is obvious. The yellow stars were found to be the nearest on the whole, and to lie within comparatively narrow limits of distance. At great distances the stars thin out, either owing to reaching the limits of the stellar system, or to the absorption of light in space.

Distribution of the Stars.—The distribution in space of the proper motions in Boss's *P.G.C.* has been analysed by E. von der Pahlen (*Ast. Nach.* 4725). His results indicate that about 80 per cent. of these stars appear to be moving towards the solar antapex, and that a section of the velocity surface by a plane through the galactic axis—instead of being an ellipse, as in Schwarzschild's theory—is more of the nature of a lemniscate, the short axis of which joins the galactic poles. K. Schwarzschild (*Ast. Nach.* 4740) finds from a summary of Kapteyn's parallaxes that there is a rapid increase in the ratio proper motion/parallax with the magnitude, whereas general considerations indicate that these two quantities should be proportional. An investigation of this result indicates that there is a dependence of the velocity upon the intrinsic brightness of a star, as is indicated also by radial velocity results, but that the discrepancy is also due partly to the fact that when taking the mean proper motions there is a more rigid exclusion of large proper motion stars than there is when taking the mean parallax.

In *Memoirs, R.A.S.*, lx., pt. iv., S. Chapman and P. J. Melotte publish the results of counts of the number of stars of each photographic magnitude down to 17^m.0, in different galactic latitudes, based upon a series of counts made with the Franklin-Adams chart plates, the magnitudes being standardised by means of plates taken with the 30-inch reflector and 26-inch refractor at Greenwich. The chief results obtained are that—over the range of magnitudes considered—the galactic concentration is sensibly constant, a result in contrast to Kapteyn's estimates, and some other visual estimates, such as the Herschel star gauges; and that the total number of stars N_m down to magnitude m can be represented very closely by means of the formula

$$N_m = a \int_{-\infty}^{\beta(m-\gamma)} e^{-x^2} dx.$$

By a not improbable extrapolation the total number of stars is deduced. It is concluded that this number "is not less than one thousand million, and cannot much exceed twice this amount."

The position of our solar system relative to the galactic plane is known tolerably accurately from counts of stars in different galactic latitudes, but little is known about the displacement parallel to the plane, and its determination is difficult and uncertain. O. W.

Walkey (*M.N., R.A.S.*, lxxiv. p. 469) has attempted to determine this by means of counts of stars in different galactic longitudes. He finds that the Cygnus region of the Milky Way is nearer to us than that in Argo, and that the richest direction lies between 238° – 243° galactic longitude. This leads to a position of the "sidereal centre" on a line α $6^{\text{h}} 0^{\text{m}}$, δ – 55° to α $6^{\text{h}} 55^{\text{m}}$, δ – 52° . Later (*Knowledge*, xxxvii. p. 287) he has put forward the suggestion that Canopus forms the sidereal centre, and has advanced arguments in favour of this view.

H. N. Russell and H. Shapley find (*Astroph. Journ.*, xl., Dec. 1914) that the eclipsing variables show a strong concentration towards the galactic plane. A similar result has been found by Hertzsprung (*Ast. Nach.* 196, p. 205, 1913) for short-period variables.

Stellar Dynamics.—H. H. Turner has suggested that the stars move in elongated orbits under the general attraction of the stellar system, and that the two star streams are really the aggregate of the stars moving respectively to and from the centre. On this theory, the third stream—Drift O—finds a natural explanation (*M.N., R.A.S.*, lxxv. p. 2) in the supposition that it is the aggregate of the stars which have reached the pause positions at the ends of their orbits. This would explain the great average distance of the stars of this stream, and also the fact that they are at rest in space. That the helium stars mainly belong to this stream is explained by supposing that they were formed at the same time and have reached their pause positions together.

Mention must be made of the publication during the year of *Stellar Movements and the Structure of the Universe*, by A. S. Eddington, which provides a comprehensive summary and discussion of our present knowledge of star-streaming and of other problems connected with stellar distribution and dynamics.

H. S. J.

Errors in Right Ascension of the Fundamental Star Catalogues.

In the Greenwich Second Nine-Year Catalogue for 1900 a comparison was made between results based on twelve-hour groups and the fundamental catalogues of Newcomb, Boss, and Auwers. The comparison indicated the possibility of systematic errors affecting all three fundamental catalogues. Recently the subject has been taken up by several investigators, who have employed material collected at a number of different observatories. All the investigations agree in indicating errors in a definite direction, although the agreement is not quite perfect as to the magnitude of the quantities. It is quite possible that a large part of the difference between the catalogues and the most recent observations is due

to erroneous proper motions introduced through errors in old observations. The following papers deal with this subject:—

Thackeray, *M.N.*, lxxi. p. 174 (1911).

Hough, *M.N.*, lxxiii. p. 138 (1913).

Cohn, *A.N.*, 4668 (1913).

Eichelberger and Morgan, *A.J.*, xxviii. p. 157 (1914).

Thackeray employed the Greenwich observations 1860–1909. Hough considered recent observations made at the Cape, Pulkowa, Odessa, and Greenwich. Cohn's paper, which is a discussion and extension of the two earlier ones, makes use of Auwers-Bradley and the Pulkowa observations from 1845, as well as modern observations. Eichelberger and Morgan only use observations made at the U.S. Naval Observatory, 1903–11.

As the investigations involve quantities of the order of $0^{\circ}.001$ great precautions have to be taken to free the observations from error. The magnitude equation is of the order of $0^{\circ}.007$ per magnitude, and so its effect must be eliminated. Thackeray employed only stars between magnitude 3.0 and 4.9; Hough chose stars so that the mean magnitude did not vary greatly with the R.A.; Eichelberger and Morgan used a screen to cut down all stars to magnitude between 6 and 9. As the error might vary with declination it is important to use stars fairly near the equator. The question of declination is gone into very fully by Eichelberger and Morgan, who separate the results into 10° zones from -20° to $+30^{\circ}$. It is of course essential that stars observed on one night should extend at least 6 hours in R.A. and preferably 12 hours. At most observatories this is accomplished by making observations at one end of the series in daylight. This requires a discussion of possible discordances due to difference of day and night illumination of the field. In the U.S. Naval Observatory only night observations have been used, with the average period of observation extending for 10 hours. When observations extend over many hours it is necessary to have a very stable instrument whose errors can be easily and accurately determined, and it is necessary to have a clock with a steady rate.

For comparison we shall reduce all the results to the form of corrections to Boss, using where necessary the formulæ, given by Hough, connecting one fundamental catalogue with another. [This is not quite accurate except for 1910. Differences in the proper motions of the fundamental catalogues will very slightly affect the formulæ.] The corrections are written in the form

$$A_1 \cos a + B_1 \sin a + A_2 \cos 2a + B_2 \sin 2a.$$

Thackeray obtained the following corrections: that for 1880 is from the mean of all the catalogues used, that for 1908 is from recent observations:—

	A_1 s	B_1 s	A_2 s	B_2
1880	−.0022	−.0011	+.0000	−.0035
1908	+.0012	−.0124	+.0026	+.0016

Thackeray's corrections to the proper motions will be referred to later. Hough used these corrections to reduce all his data to 1910, and obtained the following results:—

Observations.	$\overset{s}{A}_1$	$\overset{s}{B}_1$	$\overset{s}{A}_2$	$\overset{s}{B}_2$
Cape (1910)	+ '0103	— '0113	+ '0114	— '0033
24 Odessa Stars (1900)	+ '0073	— '0135	+ '0075	— '0041
78 Odessa Stars (1900)	+ '0094	— '0116	+ '0113	— '0025
24 Pulkowa Stars (1905)	+ '0061	— '0075	+ '0114	+ '0011
Greenwich (1900)	+ '0057	— '0092	+ '0065	— '0023
Mean	+ '0078	— '0106	+ '0096	— '0022

Cohn gave a new discussion in which he did not assume any proper motions. His results are:—

Observations.	Epoch.	$\overset{s}{A}_1$	$\overset{s}{B}_1$	$\overset{s}{A}_2$	$\overset{s}{B}_2$
Cape (Hough's result)	1910	+ '0103	— '0113	+ '0114	— '0033
92 Odessa Stars	1900	+ '0078	— '0096	+ '0027	— '0012
276 Pulkowa Stars	1905	+ '0040	+ '0009	+ '0074	+ '0019
Greenwich (Hough's result)	1900	+ '0042	— '0046	+ '0042	— '0013
Mean	1904	+ '0066	— '0062	+ '0064	— '0010

If Thackeray's proper motions are used to reduce all the results to 1910 the agreement is closer.

Eichelberger and Morgan's paper leads to the following corrections to Boss's catalogue for 1907:—

$$\begin{array}{cccc} \overset{s}{A}_1 & \overset{s}{B}_1 & \overset{s}{A}_2 & \overset{s}{B}_2 \\ + '010 & - '003 & + '003 & - '001 \end{array}$$

From observations made at San-Luis, Boss gave the corrections to his catalogue for 1910 as—

$$\overset{s}{+ '009 \cos \alpha} \quad \overset{s}{- '008 \sin \alpha}$$

The general result of all the investigations therefore gives the following corrections to the catalogues of Newcomb, Boss, and Auwers for an epoch about 1907:—

$$\begin{array}{cccccc} \text{Newcomb} & \overset{s}{+ '006 \cos \alpha} & \overset{s}{- '012 \sin \alpha} & \overset{s}{+ '006 \cos 2 \alpha} & \overset{s}{+ '002 \sin 2 \alpha} & \\ \text{Boss} & \overset{s}{+ '008 \cos \alpha} & \overset{s}{- '007 \sin \alpha} & \overset{s}{+ '006 \cos 2 \alpha} & \overset{s}{- '001 \sin 2 \alpha} & \\ \text{Auwers} & \overset{s}{+ '008 \cos \alpha} & \overset{s}{- '008 \sin \alpha} & \overset{s}{+ '006 \cos 2 \alpha} & \overset{s}{+ '001 \sin 2 \alpha} & \end{array}$$

Thackeray's paper is the only one which gives corrections to Boss's proper motions. The corrections to Auwers have been

5919.2

given by Thackeray and Cohn. The results for centennial proper motions are—

	A_1 s	B_1 s	A_2 s	B_2 s
Thackeray	+ '023	- '049	+ '016	+ '000
Cohn I.	+ '004	- '006	+ '013	+ '013
Cohn II.	+ '012	- '011	+ '001	+ '003
Cohn III.	+ '010	- '009	+ '004	+ '005
Cohn (Mean)	+ '009	- '009	+ '006	+ '007

Thackeray's results are based on Greenwich observations alone ; Cohn I. depends only on Pulkowa observations, Cohn II. on Auwers-Bradley and the mean of Pulkowa, and Cohn III. on Auwers-Bradley (half-weight) and Pulkowa. The results agree only in sign.

The relative magnitude of the coefficients may have a simple explanation. The proper motions of Auwers' catalogue depend to a large extent on the same old observations as Cohn's discussion ; on the other hand, considerable systematic corrections were applied to the older Greenwich catalogues. It should be noted also that for the Greenwich catalogue of 1860 Thackeray's result depends on a new discussion of the twelve-hour groups. The lapse of time and the increasing accuracy of modern observations should soon yield satisfactory corrections to the proper motions. J. J.

Astrographic Chart and Catalogue.

It is believed that, in general, this work is proceeding in the directions indicated in previous Reports, there being the specific information to add that the 1360 Catalogue plates of the zone 24° to 31° S. declination allotted to the Cordoba Observatory have all been taken, and that according to Dr. Perrine's report for 1913, 564 of these had been measured up to the end of that year.

As to the progress of the work of the zone 17° to 23° S., which was divided between three observatories at the Conference of 1909, it is learned from a recent report by Mr. Pocock that the astrographic telescope of the Nizamiah Observatory, Hyderabad, has been set in good order, that a few plates have been measured, and that arrangements for co-operation have been made with the Observatory of Santiago de Chile, which is one of the participators in the work of this zone. At the third of these observatories, that of the University of La Plata, now under the direction of Professor W. J. Hussey, a new object-glass has been fitted in place of the original, which had been accidentally broken, and the instrument appears to be ready for use.

The first instalment of the Cape Catalogue has been distributed during the year, bearing the title *Cape Astrographic Zones*, vol. i. This contains the standard rectangular co-ordinates and diameters

of star-images on the 144 plates which make up the zone, whose centre is at declination 41° S. Eleven such zones, containing 1512 plates in all, with centres from 41° to 51° S., complete the Cape section of the *Astrographic Catalogue*. The original co-ordinates were measured with a micrometer-screw, and their equivalent values are given in minutes of arc to the third decimal place, with positive or negative sign, all images within $60'$ from the centre of the plate in either direction in each co-ordinate being measured. The co-ordinates are "standard," that is, they are the original measures corrected by application of the plate-constants, the list of which is given in the Introduction. These constants have been computed by the use of stars taken from the *Cape Catalogue of 8650 Astrographic Standard Stars*, which was derived from meridian observations made with the transit-circle during the years 1896-1899 inclusive, the plates of this volume having been taken mainly between 1898 and 1901. An estimate of the magnitude of each star is given, either in terms of a unit ($=4''.5$) or in the case of the fainter stars by a figure which indicates the estimated density of the photographic image on an arbitrary scale. A second volume of this kind is complete, and will shortly be issued.

The third volume of the *Greenwich Astrographic Catalogue* has been completed and distributed during the year. This is a catalogue of the Right Ascensions and Declinations for 1900.0 of 16780 selected stars deduced from rectangular co-ordinates given in volumes i. and ii. with their magnitudes taken from the *Bonn Durchmusterung*, and also their photographic magnitudes based on the Harvard scale of photographic magnitudes. Comparisons of the star places with those of Carrington's Catalogue, and with the catalogues of the Astronomische Gesellschaft, which cover the zone 64° to 80° N. Dec., are given, and a catalogue of the rectangular co-ordinates of 2212 stars within 3° of the North Pole mentioned in a previous report is also included in the volume.

The photographic magnitudes and the proper motions of stars deduced by help of the places in this Catalogue have formed the basis of various papers already presented to the Society.

The total number of enlarged reproductions of chart-plates distributed by different observatories up to the end of 1914 is given in the table below. The French observatories are issuing reproductions of alternate zones only. At the Royal Observatory, Greenwich, chart-plates of the zone 25° to 31° N. Dec., of which the Catalogue has been made at the Oxford University Observatory, are being taken, with two exposures of thirty minutes each.

Algiers . . .	484	Rome . . .	56
Bordeaux . . .	253	San Fernando . . .	427
Brussels . . .	80	Tacubaya . . .	353
Paris . . .	500	Toulouse . . .	304

H. P. H.

Optical Interference Methods in Astronomy.

A considerable addition to our knowledge of the nature of nebulae has been made recently by MM. Bourget, Buisson, and Fabry, and their method promises to be of great value for further application to astronomy. It is a development of some ideas which can be traced back to Michelson (*Ap. J.*, ii. p. 251), and has for its object the determination of the temperature of a gas, or the mass of the particles, by measuring the widths of the emitted spectrum lines. These widths are determined by an indirect method, on account of their extreme smallness in the circumstances to which the theory is applicable. Light from a source—this source being a slit which is sufficiently narrow to admit only the passage of a single spectral line formed by a spectroscope—is focussed by a converging lens-system. It then passes through two parallel plates. On emergence, it contains two components, which are parallel. One has passed straight through, and the other has been reflected by the inner surfaces between the plates. Their lengths of path are different, and can be made of any order of magnitude by altering the distance between the plates. Rays reflected inside the glass plates can be removed by simple methods, and present no disturbing factor.

Two rays interfere when their path-difference is an odd number of half-wave lengths, if the light is homogeneous, as in a monochromatic spectrum line. If the light is ultimately received in a telescope focussed to infinity, the field of view will contain a set of concentric dark rings, corresponding to pairs of rays which fell on the plates at angles which implied this difference of path. If the light is not homogeneous, the dark rings for the red end of the spectrum line will not quite coincide with those from the violet end, and the divergence will become more and more pronounced as the difference of path is increased. As the plates are separated, a stage is reached at which extinction for one end of the line and complete reinforcement for the other occur, simultaneously, and the rings become invisible. If N is the number of complete waves then contained in the path-difference,

$$N\Delta = \lambda$$

where Δ is the width of the spectrum line, and λ its mean wavelength. Observations of N allow us to deduce Δ .

If the width of the line is due only to the Doppler effect of the motion of the emitting particles—as determined by the kinetic theory of gases—the calculation of Lord Rayleigh and Schönrock show that

$$\Delta = 0.82 \times 10^{-6} \times \lambda \sqrt{\frac{T}{m}}$$

where T is the absolute temperature of the gas, and m the mass of the emitting particle. Accordingly

$$N = 1.22 \times 10^6 \sqrt{\frac{m}{T}}.$$

There are, of course, other causes of widening of a line. The widening due to shocks, say Δ_1 , is given for example by

$$\frac{\Delta_1}{\Delta} = 0.61 \frac{L}{\lambda},$$

where L is the mean free path of the particles. In ordinary Geissler tubes, Δ_1/Δ is negligible, and the application of the method to nebulae presupposes that the degree of exhaustion there is of a similar order to that in a Geissler tube. Schonröck's formula was verified in a remarkable manner for the inert gases, helium, neon, and krypton contained in such tubes. The series spectrum of hydrogen gave less satisfactory experimental results, perhaps because the lines are double. The secondary spectrum, on the other hand, gave good results, and was shown to come, at least in great part, from the atom, and not the molecule.

M.M. Buisson and Fabry have experimented on some iron lines in the solar spectrum, and found their results to be in accord with a temperature of 6000°C .—with some assumptions concerning the mean free path. In 1911 they commenced the study of the Orion nebula, and more particularly of its double line near $\lambda 3729$. Their interference methods have in the first place determined the wave-lengths exactly as 3726.100 and 3728.838 , against Wright's values 3726.2 ± 0.2 , 3728.8 ± 0.2 . These values establish the fact that they correspond to no known terrestrial lines. They are on the international scale, for a source at rest with respect to the observer.

One of the best applications of interference methods in astronomy is to the determination of absolute radial velocities. This can only be done by the absolute measurements of wave-lengths of lines known in terrestrial sources. The hydrogen line H_γ has been employed in the case of the Orion nebula, and the mean radial velocity in this nebula, with respect to the Sun, is 15.8 kilometres per second. Previous observations by Keeler, Wright, Vogel, and Frost and Adams have given 17.7 , 16.2 , 17.4 , 18.5 , and the general agreement is satisfactory, as we are uncertain whether all the results pertain to the same regions of the nebula.

The above applications do not depend in any way on the *width* of the spectrum line, but are only the results of a precise determination of wave-lengths. Applications of the theory outlined above have been made to the components of the doublet $\lambda 3729$, and to the hydrogen lines. If, as is natural, the hydrogen and the other components have the same temperature, and if N_1 , N_2 are the orders of interference for a hydrogen line λ_1 and

another line λ_2 , the masses of the emitting particles are in the ratio

$$\frac{m_1}{m_2} = \left(\frac{N_1}{N_2} \right)^2.$$

Observations of N_1 and N_2 give this ratio, and since m_1 is the mass of a hydrogen atom, $\frac{m_2}{m_1}$ is the atomic weight of the gas which produces the line λ_2 . The atomic weight of archonium, the name given by Nicholson to the gas producing the doublet $\lambda 3729$, is found to be about 2.74, very close to the value found by Nicholson in his theory of the nebular spectrum. It supports the view that the nebulae contain non-terrestrial elements. The atomic weight of nebulium, the source of the line $\lambda 5007$, has been shown by visual methods only to be greater than 1 and less than 2.94. This line is therefore due to yet another new element.

The absolute breadths of the hydrogen lines in the nebula, arising from a particle of known mass, give the absolute temperature of the nebula. The result obtained is about $15,000^\circ \text{C}$. This value is probably too high, for any cause, such as loss of light in the apparatus, which tends to make the fringes disappear too soon,—that is to say, for too small a path-difference—leads to a smaller value of N , and therefore a larger value of T , as the formula shows. This absolute measurement may therefore be somewhat unreliable. But such a cause, whatever its nature, would probably operate equally for all lines in the spectrum, and leave the ratio N_1/N_2 unaltered. Considerable confidence may therefore be attached to the determinations of atomic weights.

A critical justification of the method on theoretical grounds has just been given by Lord Rayleigh (*Phil. Mag.*, Feb. 1915).

J. W. N.

Stellar Spectroscopy in 1914.

The development of Professor Nicholson's investigations into the nature and origin of spectra has been continued with remarkable results, and may justly be picked out as constituting the most notable and stimulating advance in the year. He proceeds from the conception that in celestial bodies, those which astrophysicists have come to place earliest in the order of evolution may be in conditions of radiation which are more primordial than those which we have been able to reproduce in the laboratory, and that it may be in consequence of this that they evade our efforts to assign origins from our knowledge of terrestrial spectra to the lines seen in their spectra. At first, in his work on the relationship of lines measured in nebulae (*M.N.*, 72, 49) and in the corona (*M.N.*, 72, 139, 677, 729), he discovered ratios between wave-lengths, and was able to compare them with the ratios of wave-lengths

corresponding to periods which he assigned, by the principles of Newtonian dynamics, to disturbances in the steady motion of rings of different numbers of electrons circulating round simple nuclei, conceived on the lines of Rutherford's model atom (1911), and treated by methods analogous to those developed by J. J. Thomson in relation to his model atom (1904). Rutherford's model differs from Thomson's mainly in the concentration of the positive nucleus, a concentration which, while it affords an explanation of various physical phenomena, such as the observed deflection of α particles by atoms, leaves the stability of the atom and the maintenance of monochromatic radiation more difficult of explanation, but gives to the mathematical analysis freedom to utilise the inverse square law of force between the positive nucleus and the circulating negative electrons.

Nicholson, regarding it as legitimate to assign terrestrial spectra in general to atoms or molecules or molecular aggregates with compound nuclei, has searched for evidence that simple nuclei with positive charges equal to the integral multiples of the electronic charge, surrounded by circulating rings of negative electrons, might be responsible for the lines of unknown origin in the earliest celestial bodies. He has met with a success which one would ordinarily be inclined to connect only with a magician's wand.

He has deduced the periods of disturbances, in and perpendicular to the plane of the rings, in such simple-ring atoms. He finds that the periods are related in many cases in ratios identical with those of the periods of lines detected in the nebulae, and so again in the solar corona. Thus many of the nebular lines correspond with the disturbances in systems consisting of nuclei with $\nu=4$ positive charges, surrounded by rings of n electrons from $n=2$ to $n=6$. There are also signs, in the nebulae, of systems with nuclei whose positive charges range from $\nu=2$ to $\nu=6$.

The amenable lines in the spectra of Wolf-Rayet stars are found to be nearly completely grouped under a single formula, in which the key wave-length is that of a line assigned to the atom of neutral nebulium ($\nu=4$). The formula has the form

$$\lambda = \frac{2\lambda_0}{1 + nd} \left(\frac{m^2}{m^2 - q^2/4\omega^2}, \frac{m^2}{m^2 - 1} \right),$$

where the key wave-length λ_0 for the element responsible for most of the Wolf-Rayet lines is the nebulium line 5007, and n is an integer the value of which would seem to be an indicator of some evolutionary process, so that a change of n denotes a transition to a substance of different internal constitution, whilst, for a given n , lines corresponding to a variable m arise from the same atom. Thus the substance responsible for the Wolf-Rayet spectrum is to be regarded as an evolutionary product of nebulium. His assignment of the Balmer hydrogen series to an evolutionary product of a more elementary simple-ring atom in the evolution of matter is a beautiful illustration of the originality of his investiga-

tion (*M.N.*, 74, 204), and one's Pythagorean instincts are strangely satisfied by his finding that hydrogen is derivable from the simple-ring system for which the nuclear charge νe is given by $\nu = 1$.

The comparison of the periods of these simple-ring atoms and their evolutionary products with periods recognised in the earlier celestial spectra seems to have been carried out by Professor Nicholson with unwavering impartiality, and though the chance that the coincidence of the ratios of theoretical wave-lengths with those of celestial lines is fortuitous was calculated in the earliest stages (*M.N.*, 72, 64), and found to be exceedingly small (5 in a million for nebulium), yet as the investigation has developed one becomes anxious lest in the wealth of periods deduced from systems of nuclear strength ranging from e to $6e$, and with rings ranging from 1 electron to 8, the chance of fortuity has been vastly increased. The summary of the accumulated evidence which Dr. Nicholson has promised will be very welcome. Meanwhile an attempt is made in the following table to show in rough synoptic form the primary systems, the evolutionary products, and the distinctive spectral lines assigned to each. It may be noted that the green line $\lambda 5303$ of the corona has hitherto evaded his efforts to assign a place to the hypothetical coronium in the new scheme.

Positive nuclear charge = νe	$\nu = 1$	2	3	4	5	6	7	8
Atomic weight $= \frac{1 \cdot 31}{16} \cdot \nu^2$	0.082	.33	.74	1.31	2.05	2.95	4.01	5.24
Primary simple-ring systems	Protohydrogen.			Nebulium.	Protofluorine.	Archonium.		
Recognised habitat	Nebulæ	Nebulæ Nova Persei	Nebulæ	Nebulæ	Corona	Nebulæ		
Principal wave-length	1823.55	3869	5185	5007	3987	3729		
Evolutionary products	Balmer hydrogen	Not yet named		Not yet named		Not yet named		
Recognised habitat	Earth, nebulæ, stars	Wolf-Rayet stars		Wolf-Rayet stars		Wolf-Rayet stars		
Principal wave-lengths	H α , H β , etc.	5158 4353	4967	6583 5813 4652		3484		

It is questionable, as Dr. Nicholson has pointed out, whether the name protohydrogen, which has been chosen for the earlier element from which hydrogen proper is supposed to be evolved, can be given without regret. Lockyer's nomenclature has a

significance which is at variance with Nicholson's avowed belief that the Balmer series may be due to enhanced hydrogen. After the modern transformations of the atomic theory, it would be rash to assume that we are in sight of approximate finality. Until we can do so, however, there might be advantages in adopting a provisional descriptive nomenclature of the nine simple-ring systems. Nicholson's researches indicate these nine as the only possible systems, and his reference to the vacant places in the early rows in the Periodic Table of chemical elements suggests the appropriation of descriptive names such as might be afforded by the Greek numerals proton, deuteron, triton, tetarton, etc.

It is hardly possible to summarise briefly Nicholson's varied attacks on what may be called the physical problem. Some of the most interesting parts of his numerous papers relate to his treatment of Planck's conceptions as modified by Sommerfeld, Larmor, and others. He shows, first in the case of protofluorine ($\nu=5$), that there is a simple relation between the angular momenta of simple-ring systems and Planck's constant; and this enables him to assign the absolute dimensions of the atoms. The discrepancies between the treatments adopted by Nicholson and Bohr seem likely to lead to a very marked advance in the dynamics of line spectra. A searching study of them, such as each of these investigators is making, promises to prove a very clarifying influence.

Reference may here be made to another such influence, viz. the masterly report of J. H. Jeans on Radiation and the Quantum Theory (*Phys. Soc.*, 1914). In a general reflection about the problem of line spectra (§ 43), Jeans remarks that whereas Rydberg's constant, entering similarly into all series spectra of terrestrial elements, would seem to receive a natural interpretation as depending on quantities common to all kinds of matter, and thus to be a function only of e , m , and c (the velocity of light), it is necessary to add another quantity of the dimensions of the quantum in order to construct the Rydberg constant of proper physical dimensions. Planck's constant supplies the omission exactly.

Thus we see that Nicholson's endeavour to give an atomic foundation to Planck's theory gains additional interest, all the greater in connection with G. W. Walker's success in deriving an expression for total radiation as satisfactory as Planck's though based on dynamical principles (*Proc. R.S.*, **89**, 393), and his attempt to formulate the dynamics of an atomic model, which takes account of rotational and magnetic effects (*Proc. R.S.*, **91**, 156).

One more reflection may perhaps be permitted. If it be true that in Nicholson's work some of the observed lines seem to be rightly assignable to more than one of the theoretical origins, this might be taken as indicating the possibility of explanation of the apparently arbitrary manner in which certain lines in complex terrestrial spectra (*e.g.* in the cases of oxygen, nitrogen, silicon) are

picked out in stellar spectra (*e.g.* of type A and B). It looks as if the case for assigning different lines or sets of lines to different vibrating systems in a gas in a given state of complexity might be developed in such a way that by the appropriate excess of certain of these systems under changed conditions definable in terms of electric complexity, stress might be laid on lines which though weak in ordinary terrestrial conditions become strong under the changed conditions. Nicholson has pointed out that there are indications that we may have a positively electrified chromosphere and a negatively electrified corona.

Nebulae.—MM. Fabry, Buisson, and Bourget (*Ap. J.*, **40**, 241) have made further advances in their study of the Orion nebula by the method of the interferometer.

Professor Nicholson (*M.N.*, **74**, 623) points out that observations made at Helwân, and reported by Mr. Reynolds (*Observatory*, p. 199), show that the line 3729 in the Orion nebula has a different origin from the line 5007, and emphasises Fabry and Buisson's results as supporting the view that the ultra-violet line is to be assigned to the element archonium with nucleus $+6e$ and atomic weight about 3.

W. H. Wright (*M.N.*, **75**, 20) calls attention to the fact that in the many nebulae observed by him the lines 3726 and 3729 maintain fairly constant relative intensities, and this has a direct bearing on the work of Professor Nicholson, who points out that the observations of Fabry and Buisson indicate a common origin.

W. H. Wright (*Ap. J.*, **40**, 466), in studying the spectrum of the planetary nebula, *N.G.C.*, 6572, has been able to secure a spectrogram which isolates the spectrum of the nucleus from that of the outer parts. The nucleus shows broad emission bands at 4057, 4633, 4649, 4686, and 5807, superposed on continuous background, whilst the nebular lines appear in the outer parts and across the nuclear spectrum. These five bright bands indicate that the nucleus of the nebula is a Wolf-Rayet star.

V. M. Slipher (*Lowell Obs. Bull.*, No. 62) has detected in spectrograms of the spindle-shaped nebula in Virgo, *N.G.C.*, 4594, indications of rotation. The nebular lines show very large shift, indicating a very high translational velocity, and the lines are also inclined so markedly as to indicate rotation at first inspection. This nebula is figured in Roberts's *Celestial Photographs*, vol. ii., plate 20.

Novæ and Stars with Bright Lines.—W. S. Adams and F. G. Pease (*Ap. J.*, **40**, 294) record their success in obtaining spectrograms of four temporary stars, Nova Aurigæ (1891), Nova Persei (1901), Nova Lacertæ (1910), Nova Geminorum No. 2 (1912), of magnitudes 14, 12.4, 12.5, 10 respectively. The most interesting feature is the absence of the chief nebular lines 4960 and 5007 and of the line 4364 usually associated with them from

the spectra of Nova Aurigæ and Nova Persei. The eventual similarity of these novæ to Wolf-Rayet stars is interesting, taken in connection with the well-known agreement of distribution relative to the Milky Way. The plate illustrating the paper is a remarkable achievement, the stars being so faint.

In a memoir issued from the Solar Physics Observatory (1914) under the title "On Some of the Phenomena of New Stars," Sir N. Lockyer, Mr. Baxandall, and Mr. Rolston give a valuable summary, and discuss among other matters a remarkable set of early spectrograms of Nova Geminorum No. 2 obtained by Professor Iniguez at Madrid in 1912 March and April.

J. S. Plaskett (*Ottawa Publ.*, i., No. 6) records observations of the early spectra of Nova Geminorum No. 2.

V. Fontana (*Spett. Ital.*, ii. 201) describes observations of the spectrum of Nova Geminorum No. 2.

J. H. Moore and R. F. Sandford (*L.O.B.*, viii. 55, No. 252) discuss their measures of the remarkable spectrum of η Carinæ (= η Argus). The similarity of the spectrum with that of novæ in their early stages may be taken as justification of inclusion of the reference to this work under the heading Novæ. The paper is illustrated by a remarkable photograph.

Special Studies.—W. S. Adams (*Ap. J.*, **39**, 89) has obtained photographs of pairs of spectra of stars, one of large proper motion, the other of small proper motion. A comparison of the intensity at several wave-lengths should for individual stars afford material for investigating Kapteyn's question as to the absorption of light in space. Out of 20 pairs investigated, 14 pairs show a marked difference, and in every case the star of small proper motion is relatively weak at the violet end of the spectrum.

J. C. Kapteyn (*Ap. J.*, **40**, 187) collects the available evidence on the change of spectrum and colour index with distance and absolute brightness.

A. Hnatek (*Ast. Nach.*, **198**, 33) contributes a paper on the relation between the temperatures and diameters of stars.

E. Freundlich (*Ast. Nach.*, **198**, 265) compares the redward displacement observed in lines in the solar spectrum with expectations based on Einstein's views about the influence of gravitation on light.

P. Nashan (*Ast. Nach.*, **197**, 289) deals with the relation between colour, spectrum, and parallax of the stars.

C. P. Janssen (*Ast. Nach.*, **197**, 385) publishes a short note on velocities and temperatures of stars.

W. W. Campbell (*L.O.B.*, viii. 82) calls attention to the evidences of rapid convection in stellar atmospheres.

E. B. Frost and F. Lowater (*Ap. J.*, **40**, 268) have measured the spectrum of ι Lacertæ. The results derived from 15 plates give the wave-lengths of certain lines of special interest as follows: 4685.90, 4116.33, 4097.55, 4089.12. The star is placed by Miss Cannon in class Oe 5. It has, like many stars of this class, a

variable velocity. The period is short but is as yet undetermined. The work throws no light upon the discrepancy + 5 km/sec in determinations of radial velocity of B stars.

Classification and Distribution of Stellar Spectra.—H. N. Russell's admirable address on the relations between the spectra and other characteristics of the stars (*Nature*, **93**, 227, 252) is referred to in a special note (p. 326).

W. S. Adams and A. Kohlschütter (*Ap. J.*, **40**, 385) contribute a valuable paper on spectral criteria for the determination of absolute stellar magnitudes.

F. W. Dyson (*M.N.*, **74**, 733) treats of the proper motions of the stars in Carrington's Circumpolar Catalogue in relation to their spectral type, the type being for these purposes taken from the colour indices by a comparison with the results recorded in the *Harvard Circular*, 180.

In the *Annals of the Harvard College Observatory*, vol. **76**, No. 2, are recorded the results of a systematic comparison of various star catalogues in relation to the colour index.

H. N. Russell and H. Shapley (*Ap. J.*, **40**, 417) have studied the distribution of eclipsing variables in space, and arrive at the result that a large majority lie within a region bounded by two planes 1000 light-years apart and parallel to the galactic equator whose median plane passes about 100 light-years south of the Sun. Almost all the rest lie within 500 light-years on each side of this region. Within it the stars extend in all directions to the limit of 8000 light-years, if space is transparent.

Miss Cannon discusses a large number of celestial spectra which are characterised by bright lines (*H.C.O. Ann.*, **76**, No. 3). The fainter objects were photographed at Harvard and at Arequipa with dispersion 2 mm. between H_{β} and H_{ϵ} , the others with a dispersion three times as great. The available material relates to 750 celestial objects, and they may be divided as follows into at least six classes:—

- 150 gaseous nebulæ of Class P.
- 107 fifth-type spectra of Class O.
- 10 of P Cygni type.
- 20 novæ.
- 99 stars of Class B with bright hydrogen lines (β Lyræ).
- 364 stars of Class Md.

The paper deals with the first four classes, and is illustrated by two plates of photographic reproductions.

The *Harvard Circular*, No. 184, contains information about 14 stars with peculiar spectra and 24 stars having composite spectra.

F. E. Baxandall, in papers issued from the Solar Physics Observatory (1914) under the title "Comparison of the Spectra of Rigelian, Crucian, and Alnitamian Stars," discusses the spectra

of β , γ , ϵ , ζ , κ , and ι Orionis, and also the spectra of α Orionis and γ Cassiopeiæ.

Radial Velocities.—The radial velocities of 100 stars with measured parallaxes have been determined by W. S. Adams and A. Kohlschütter (*Ap. J.*, **39**, 341). The stars range in magnitude between 5.2 and 8.2, and in parallax (Kapteyn, *Groningen*, No. 24) between $-0''.12$ and $+0''.30$, and in absolute magnitude between 3.4 and 10.6 (Sun 5.5). Out of 20 stars with velocities greater than 50 km/sec there are 15 with negative velocities (highest -325) and only 5 with positive velocities (highest $+100$). Nearly all spectral types are represented:—1B, 5A, 23F, 46G, 23K, 2Ma. Two stars of type A are found to have high velocities (-151 and -158 km/sec), though Campbell finds none (among his 337) with velocities exceeding 40 km/sec, and the Mount Wilson observers have found only 1 out of 350 stars of types B and A with a high constant velocity. Attention may be drawn to a point which does not appear to be noted by the authors, viz. the evident indications of the well-known star streams. The tables give for each of 76 stars the velocity in space and the position of its apex.

The apices of 33 stars are clustered within 40° of the point R.A. 96° Dec. $+9^\circ$

„	11	„	„	„	40°	„	„	274°	-12°
„	0	„	found	„	40°	„	„	20°	0°
„	3	„	„	„	40°	„	„	202°	0°

The vertex of star stream I. is about R.A., 94° , Dec. $+12^\circ$, and that of star stream II. is about R.A., 274° , Dec. -12° .

The radial velocities of 227 stars of types F to M as observed at the Bonn Observatory are given by Dr. F. Küstner (*Ast. Nach.*, **198**, 409).

The radial velocities of 24 stars as observed at the Vienna Observatory are given by A. Hnatek (*Ast. Nach.*, **197**, 185).

High velocities detected in two southern stars, A.G.C. 7195 (velocity $+184.8$ km/sec), and ω Pavonis (velocity $+184.4$ km/sec), are announced by J. H. Moore (*L.O.B.*, viii. 77).

Variable Radial Velocities.—Observations of 28 stars with variable velocities are given by O. J. Lee of the Yerkes Observatory (*Ap. J.*, **39**, 39). In the case of 10 of these, variability is announced for the first time; the types are A to B9. Observations of 18 other stars previously announced as binaries are also given.

Observations of 17 stars with variable velocities are given by J. H. Moore of the Lick Observatory (*L.O.B.*, viii. 71). These relate to stars south of -15° observed at Santiago, and the types are A2 to Kp, and the stars are mostly fainter than magnitude 5.0.

Observations of 5 other stars with variable velocity are given by R. E. Wilson (*L.O.B.*, viii. 80). These relate to southern stars of type A and B.

Spectroscopic Binary Stars.—Orbits are given for the following stars :—

			P.	e.
88 <i>d</i> Tauri (A3)	Daniel	<i>Alleg. Obs.</i> , iii. 93	3 ^d .571	0.00
18 Aquilæ (B8)	Jordan	„ iii. 77	1.302	0.00
δ ₁ Lyrae (B3)	„	„ iii. 119	88.112...	0.28
δ Orionis (B1)	„	„ iii. 125	5.732...	0.096
RZ Cassiopeiæ	„	„ iii. 137	1.195...	0.052
88 <i>d</i> Tauri	Harper	<i>Ottawa Obs.</i> , i. 115	3.571	0.055
σ Geminorum	„	„ i. 265	19.605	0.022
α Boötis (F5)	„	„ i. 303	9.604	0.169
ρ Leonis (Bp)	„	„ i. 337	...	...
β Leonis (A)	Cannon	„ i. 285	1.527	0.22
ξ Persei (Oe5B)	„	„ i. 13	6.951	0.34
SZ Tauri	Haynes	<i>L.O.B.</i> , viii. 85	3.148	0.24

Lists of spectroscopic binaries under investigation at various observatories are given in the *Ap. J.*, **39**, 264.

Photometric tests of eleven spectroscopic binaries have been made by J. Stebbins (*Ap. J.*, **39**, 459) with a selenium photometer, resulting in the discovery that four of them are eclipsing binaries, β Aurigæ, δ Orionis, α Virginis, α Coronæ. No sign of light-variation has been detected in α Aurigæ or in either of the binaries of the system of Castor.

Changes in the intensities of certain lines in the spectrum of δ Cephei have been studied by I. Lehmann (*Pulkovo Bull.*, 1913, No. 59). The same writer, Mme. I. L. Balanowskaja, describes her researches on the orbit of Polaris (*ibid.*, 1914, No. 65).

Orbits have been deduced by H. Shapley (*Ap. J.*, **40**, 399) for the eclipsing binary RX Herculis from both spectroscopic and photometric observations. A combination of the elements gives the actual dimensions of the stars. Such information is now available for three binary systems.

Suggestions are made by H. Shapley (*Ap. J.*, **40**, 448) as to the nature and cause of the variation of Cepheid variable stars.

H. Ludendorff (*Ast. Nach.*, **197**, 217) gives preliminary elements of the orbit of 108 Herculis. The period is 5^d.5146. He also contributes a short note on φ Persei (*Ast. Nach.*, **197**, 219).

Work in the Laboratory.—The Bakerian Lecture by Professor Fowler is printed in the *Phil. Trans.*, **214**, 225.

A. S. King (*Ap. J.*, **39**, 139) describes his observations of the spectrum of titanium in the electric furnace at different temperatures, and in another paper (*Ap. J.*, **40**, 213) states that experiments with titanium in an atmosphere of hydrogen in an electric furnace fail to show any strengthening of enhanced lines.

R. Rossi (*Ap. J.*, **40**, 232) finds evidence that current density in sparks through hydrogen is an important factor in the widening of the lines.

J. S. Clark (*Ap. J.*, **40**, 332) gives wave-lengths of the chief lines of nitrogen and oxygen in the region $\lambda 3880 - \lambda 4700$.

An important investigation on the spark spectrum of nickel under pressures of 1 to 11 atmospheres, by E. G. Billham, is published in the *Phil. Trans. R.S.*, **214**, 359.

The spectrum of silicon has been studied by Sir W. Crookes (*Proc. R.S.*, **90**, 512).

The wave-lengths of the first six lines ($H_\alpha \dots H_\zeta$) have been determined in terms of the international unit by W. E. Curtis (*Proc. R.S.*, **90**, 605). With the accuracy attained (about 0.001 unit) the wave-lengths do not exactly conform with Balmer's formula.

Experimental methods of observing the luminous jets of metallic vapour distilled from the electric arc have been developed by the Hon. R. J. Strutt (*Proc. R.S.*, **90**, 364, and **91**), and important results have been obtained bearing on the origin of spectrum series.

A. S. King and P. P. Koch (*Ap. J.*, **39**, 213) describe the results of their preliminary application of the registering microphotometer to the study of certain types of laboratory spectra.

Reductions.—H. N. Russell (*Ap. J.*, **40**, 282) describes a convenient short method of determining the orbit of a spectroscopic binary.

H. Ludendorff (*Ast. Nach.*, **197**, 1) deals with systematic errors in measurements of radial velocities.

A. Hnatek (*Ast. Nach.*, **197**, 307) gives a comparison between measurements of stellar spectra by the ordinary micrometer method and Exner's projection method.

Albrecht (*Ap. J.*, **40**, 473) discusses systematic errors arising possibly from blended lines used in determinations of radial velocities.

Theoretical Investigations.—Notes on a possible effect of the motion of the source on the velocity of light have been published by R. S. Capon (*M.N.*, **74**, 507 and 658) and by H. C. Plummer (*M.N.*, **74**, 660).

Instruments.—J. S. Plaskett (*Jour. R.A.S., Canada*, viii. 448) gives a general account of the great reflector of 72 inches aperture to be constructed by Messrs. Brashear and Messrs. Warner & Swasey.

Hamy (*C.R.*, **158**, 81) deals with the employment of the objective prism in the determination of radial velocities of stars.

C. D. Perrine (*Ap. J.*, **40**, 481) describes an ingenious method for estimating the loss of light in stellar spectroscopes.

J. S. Plaskett (*Ottawa Publs.*, i. 173) contributes a paper dealing with the efficiency of stellar spectrographs, and gives the results of comparison of various forms: and in another paper (*Ap. J.*, **40**, 127) he deals with the choice of material of the prism and other optical parts of such spectrographs.

H. F. N.

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE CONTRIBUTED TO THE LIBRARY, ETC., SINCE THE LAST ANNIVERSARY.

The Dominion of Canada.
His Majesty's Government in India.
The Lords Commissioners of the Admiralty.
H.M. Secretary of State for the Colonies.
The French Ministry of Marine.
The French Ministry of Public Instruction.
Portuguese Minister of Public Instruction.
British Association for the Advancement of Science.
British Astronomical Association.
British Horological Institute.
Institution of Electrical Engineers.
London, University College.
Meteorological Office.
Napier Tercentenary Committee.
National Physical Laboratory.
Physical Society of London.
Royal Institution.
Royal Observatory, Greenwich.
Royal Photographic Society of Great Britain.
Royal Society of London.
Solar Physics Observatory, South Kensington.
Cambridge Observatory.
Cambridge Philosophical Society.
Cambridge University, Solar Physics Observatory.
Cardiff, Astronomical Society of Wales.
Chatham, Royal Engineers' Institute.
Dublin, Royal Irish Academy.
Dublin, Royal Society.
Edinburgh, Royal Observatory.
Edinburgh, Royal Society.
Leeds Astronomical Society.
Manchester Astronomical Society.
Manchester Literary and Philosophical Society.
Oxford, Radcliffe Observatory.
Oxford, University Observatory.
Salcombe Regis, Hill Observatory.
Stonyhurst College Observatory.
Abbadia, Observatoire.
Algiers, Observatoire.
Allegheny Observatory.
Amsterdam, Koninklijke Akademie van Wetenschappen.
Antwerp, Société d'Astronomie.
Arcetri, Reale Osservatorio.
Bamberg, Remeis-Sternwarte.
Barcelona, Sociedad Astronomica.

- Basel, Naturforschende Gesellschaft.
Batavia, Koninklijke Natuurkundige Vereeniging.
Batavia, Royal Magnetical and Meteorological Observatory.
Berlin, Deutsche Physikalische Gesellschaft.
Berlin, Königlich Astronomisches Recheninstitut.
Berlin, Königlich Preussische Akademie der Wissenschaften.
Berlin, Königliche Sternwarte.
Bologna, Reale Accademia delle Scienze.
Bonn, Königliche Sternwarte.
Bombay and Alibag, Government Observatories.
Bordeaux, Observatoire.
Bordeaux, Société des Sciences Physiques et Naturelles.
Boston, American Academy of Arts and Sciences.
Brussels, Académie Royale des Sciences de Belgique.
Brussels, Société Belge d'Astronomie.
Budapest, Magyar Tudományos Akadémia.
Calcutta, Astronomical Society of India.
Canada, Royal Society.
Cape of Good Hope, Royal Observatory.
Cape Town, Royal Society of South Africa.
Cape Town, South African Association for the Advancement of Science.
Catania, Reale Osservatorio.
Catania, Società degli Spettroscopisti Italiani.
Cherbourg, Société Nationale des Sciences.
Chicago, Society for Practical Astronomy.
Copenhagen, Kongelige Danske Videnskabernes Selskab.
Copenhagen, Observatorium.
Egypt, Survey Department.
Geneva, Observatoire.
Geneva, Société de Physique et d'Histoire Naturelle.
Genoa, Istituto Idrografico.
Göttingen, Königliche Gesellschaft der Wissenschaften.
Göttingen, Königliche Sternwarte.
Granada, Observatorio Astronómico, Geodinámico y Meteorológico.
Groningen, Astronomical Laboratory.
Halifax, Nova Scotian Institute of Science.
Halle, Kaiserlich Leopoldinisch-Karolinische Akademie.
Hamburger Sternwarte in Bergedorf.
Harvard College Astronomical Observatory.
Heidelberg, Astrophysikalisches Observatorium.
Helsingfors, Finska Vetenskaps Societet.
Helwân Observatory.
Hobart, Royal Society of Tasmania.
India, Astronomical Society.
India, Survey Department.
India, United Service Institution.
Japan, Astronomical Society.
Johannesburg, Union Observatory.

- Kasan, Université Impériale, Observatoire Astronomique.
Kasan, Université Impériale, Observatoire Engelhardt.
Kodaikáanal Observatory.
Königsberg, Königliche Sternwarte.
La Plata, Observatorio Astronómico.
Leiden, Sternwarte.
Leipzig, Astronomische Gesellschaft.
Leipzig, Königlich Sächsische Gesellschaft der Wissenschaften.
Lick Observatory.
Lille, Observatoire.
Lowell Observatory.
Lund, Astronomiska Observatorium.
Madrid, Observatorio Astronómico.
Madrid, Real Academia de Ciencias.
Marseilles, Observatoire.
Mauritius, Royal Alfred Observatory.
Meudon, Observatoire Physique de Paris.
Milan, Reale Osservatorio di Brera.
Missouri University, Laws Observatory.
Moncalieri, Osservatorio Centrale del R. Collegio Carlo Alberto.
Montpellier, Académie des Sciences et Lettres.
Mount Wilson, Solar Observatory.
Münich, Königlich-bayerische Akademie der Wissenschaften.
Naples, Osservatorio di Capodimonte.
Naples, Reale Accademia delle Scienze.
Neuchatel, Observatoire Cantonal.
Oporto, Academia Polytechnica.
Ottawa, Dominion Astronomical Observatory.
Palermo, Reale Osservatorio.
Paris, Académie des Sciences.
Paris, Bureau des Longitudes.
Paris, Bureau International des Poids et Mesures.
Paris, Dépôt Général de la Marine.
Paris, École Polytechnique.
Paris, Observatoire.
Paris, Observatoire de la Société Astronomique de France.
Paris, Société Astronomique de France.
Paris, Société Mathématique de France.
Paris, Société Philomathique.
Perth Observatory, Western Australia.
Perth, Western Australian Astronomical Society.
Philadelphia, American Philosophical Society.
Philadelphia, Franklin Institute.
Philadelphia, University of Pennsylvania.
Pomona College Astronomical Society.
Potsdam, Central Bureau der Internationalen Erdmessung.
Potsdam, K. preuss. geodätisches Institut.

Poughkeepsie, Vassar College Observatory.
 Pulkovo, Observatoire Central Nicolas.
 Rio de Janeiro, Observatorio.
 Rome, Reale Accademia dei Lincei.
 Rome, Reale Osservatorio del Collegio Romano.
 Rome, Società Italiana delle Scienze.
 Rome, Specola Astronomica Vaticana.
 San Fernando, Instituto y Observatorio de Marina.
 San Francisco, Astronomical Society of the Pacific.
 St. Petersburg, Académie Impériale des Sciences.
 Stockholm, Kongliga Svenska Vetenskaps-Akademie.
 Stockholm, Observatorium.
 Sydney, Royal Society of New South Wales.
 Tacubaya, Observatorio Astronómico Nacional.
 Talence (Gironde), Observatoire.
 Toronto, Canadian Institute.
 Toronto, Royal Astronomical Society of Canada.
 Tortosa, Observatorio del Ebro.
 Toulouse, Académie des Sciences.
 Toulouse, Observatoire Astronomique.
 Turin, Reale Accademia delle Scienze.
 Turin, Reale Osservatorio Astronomico.
 Turin, Società Astronomica Italiana.
 Turin, Società Urania.
 Uccle, Observatoire Royale de Belgique.
 Upsala, Kongliga Vetenskaps-Societet.
 Vienna, Kaiserliche Akademie der Wissenschaften.
 Vienna, K. K. Universitäts-Sternwarte.
 Vienna, von Kuffner'sche Sternwarte.
 Virginia, Leander McCormick Observatory.
 Washington, National Academy of Sciences.
 Washington, Carnegie Institution.
 Washington, Navy Department.
 Washington, Smithsonian Institution.
 Washington, United States Coast and Geodetic Survey.
 Washington, United States Naval Observatory.
 Yerkes Observatory.
 Zi-Ka-Wei, Observatoire Astronomique de Zô-Sè.
 Zürich, Naturforschende Gesellschaft.
 Zürich, Sternwarte des Eidg. Polytechnikums.
 Editors of the "American Journal of Mathematics."
 Editors of the "American Journal of Science."
 Editor of the "Astronomical Journal."
 Editor of the "Astronomische Nachrichten."
 Editors of the "Astrophysical Journal."
 Editor of the "Athenæum."
 Editor of Brown's Nautical Almanac.
 Editors of the "Bulletin des Sciences Mathématiques."
 Editor of the "English Mechanic."
 Editor of "Himmel und Erde."

Editor of "Knowledge."

Editor of "Nature."

Editors of "The Observatory."

Editors of "Popular Astronomy."

Editor of "Sirius."

Prof. A. Auwers.

Major Bishop.

J. C. Clancey, Esq.

Dr. A. C. D. Crommelin.

Rev. M. Davidson.

M. Henri Deslandres.

C. R. D'Esterre, Esq.

Dr. W. Doberck.

Sir F. W. Dyson.

Prof. A. S. Eddington.

Herr S. Enebo.

Prof. E. B. Frost.

Prof. R. Gautier.

Lady Gill.

Messrs. Grant Richards & Co.

Prof. E. Hartwig.

Ellison Hawks, Esq.

C. E. Housden, Esq.

Dr. S. Kostinsky.

F. C. Leonard, Esq.

Prof. Percival Lowell.

Dr. M. Matzdorff.

E. W. Maunder, Esq.

Arthur Mee, Esq.

Dr. O. T. Olsen.

Dr. T. N. Orchard.

Prof. E. C. Pickering.

Prof. W. H. Pickering.

J. H. Reynolds, Esq.

Prof. A. Schuster

Prof. H. Seeliger.

W. J. Simmons, Esq.

M. Carl Störmer.

M. Paul Stroobaut.

Messrs. W. Wesley & Son.

Prof. Max Wolf.

Prof. A. Wolfer.

ADDRESS

*Delivered by the President, Col. E. H. Hills, C.M.G., D.Sc., F.R.S.,
on presenting the Gold Medal of the Society to Professor Alfred
Fowler, F.R.S.*

THE Council has awarded the Gold Medal of the Society to Professor A. Fowler, F.R.S., for his spectroscopical investigations of sunspots, stars and comets, and for his successful interpretation of the phenomena by means of experiments in the laboratory, and it now becomes my pleasant duty to lay before you the grounds of this award.

In so doing I shall have, in the first instance, to ask your indulgence. For reasons which I need hardly set forth, but which will be quite obvious to all of you, the intellectual atmosphere at the present time is not very favourable to the production of a detailed critical appreciation of the results of many years' patient investigation maintained at a high level of excellence, nor indeed had I the necessary leisure to devote to this task.

If, therefore, my address falls short in any way, you must please set down all deficiencies, all omissions, all defects of any kind solely to these reasons. In particular, if I am somewhat shorter than has become customary, you must attribute my brevity not in any degree to a falling away on the part of our Medallist from the very exacting standard uniformly set by the Council for the grant of our Gold Medal, but solely to the inability of your President to do full justice to his work.

In one particular my task is an easy one. Professor Fowler is a Fellow and officer of our own Society; his work, which is along lines familiar to many of you, has been, in almost all cases, published either by us or by the Royal Society, so that it is already well known to all Fellows who attend our meetings or are sufficiently interested to read his papers. The labour of presenting a summary of it is, therefore, considerably lighter than would be the case if the Medallist were a worker in some less popular branch of our science, or if foreign periodicals had to be searched for his results. In truth, I feel that when the name of Professor Fowler has been mentioned my task is already half done, to so many of you will the justice of the Council's award be at once apparent.

Before entering into details, I should like at the outset to emphasise what I may fairly call the keynote of our Medallist's work. This is contained in the latter part of the Council's phrasing of the grounds of award "for his successful interpretation of the phenomena by means of experiments in the laboratory." It is to this I shall draw special attention. By so doing I do not mean to imply that he is the only or the earliest experimenter on these lines. His old chief, Sir Norman Lockyer, was indeed quick

to recognise that for spectroscopic research the astronomer and the physicist should walk hand in hand, or better, be combined into one person; but what I wish to emphasise is, that he has by his work solved many difficult astrophysical questions and has repeatedly brought about harmony between the laboratory and the observatory where there was previously, if not actual discord, at all events a want of complete accord.

So complete is this accord in process of becoming that we are now witnessing the strange development that not only does the astronomer appeal to the physicist to help him in his difficulties and interpret physical observations made on distant bodies—this appeal is a natural one and excites no astonishment,—but what appears at first sight unnatural is that the converse appeal is now being made and the physicist is asking the astronomer's help. We may well rub our eyes when we see the attempt to derive knowledge of the internal constitution of the atom from observations of the solar corona or nebulae; but such attempts are made, and our Medallist's work has no small bearing upon them.

With these preliminary remarks I will now attempt to present a sketch of his main lines of inquiry, taking these in the order given in the Council's award, and therefore beginning with the spectroscopic investigations of sunspots and metallic prominences.

Passing over much earlier work done by Professor Fowler while he was assistant to Sir N. Lockyer, his systematic observations on spot and prominence spectra were begun in 1903 and have been carried on continuously since then. He was not long in reaching important results, and in reducing to order the records of previous observations which, read without the keys fashioned by him, gave to the observations of these spectra every appearance of capriciousness.

Thus he early observed that in general the high-level chromospheric lines were weakened in spot spectra while low-level lines were strengthened, and at the same time he rendered signal service to other observers by systematising the method of recording the amount of "widening" of a spot line. He pointed out that what was wanted was not so much a record of the amount of widening as of the actual intensities of the lines, and that this was best accomplished by comparing the spot lines with the solar spectrum and recording their intensities on Rowland's scale. This method has now been universally adopted. From later observations, he was able to show that the general result of a critical discussion of spot spectra led to the conclusion that the lines thinned or obliterated were the Fraunhofer lines agreeing in position with high-level chromospheric lines, especially if "proto-metallic" or enhanced lines, that arc lines were very little affected, and flame lines strengthened. This suggested that spots are at a lower temperature than the surrounding photosphere, a conclusion independently reached by Hale, Adams, and Gale, which may be accepted with a considerable degree of confidence.

The fact that different groups of lines of the same element

behaved differently, which at first sight appeared puzzling and capricious, was thus reduced to a systematic principle, so that it would now probably be possible to predict the approximate intensity of a spot line, from its behaviour in chromosphere, arc, and spark, without any actual observation of it being made.

Valuable summaries of our Medallist's studies of spot spectra are to be found in his papers presented to the International Union for Solar Research, of which body he is the secretary of the Committee on Sunspots. These are contained in all the four volumes already published, and I commend them to the attention of those who wish to follow this subject more closely.

A striking and fruitful part of this research was the tracing to their source of the short hazy lines in spot spectra previously termed band lines or umbra lines. During 1905 and 1906 Professor Fowler made many attempts to elucidate the origin of these and to obtain in the laboratory experimental spectra which would indicate the element or compound to which they were to be attributed; these efforts were for a long time unsuccessful. The importance of titanium in spot spectra naturally suggested a critical comparison of these bands with the flutings of this element and of its oxide, but a close scrutiny of the spectra failed to reveal any real connection in those parts he was able to examine effectively, though it was afterwards shown by Professor Hale that the titanium oxide flutings in the extreme red are actually present in spots. The same was true of vanadium. At length in 1907 the solution was reached, and our Medallist was able to prove that these bands were due to a compound of magnesium and hydrogen, or magnesium hydride, a compound long before studied by Liveing and Dewar. Afterwards he was able to show that about 2000 lines in spot spectra were due to this compound, and that the more prominent of these could be arranged in twelve rhythmical series.

This discovery was of great interest and importance not only as indicating the presence of a new and quite unexpected compound in the vapour of sunspots, but also as identifying such a large number of lines that subsequent study was much simplified. With the presence of titanium oxide, observed by Hale, and of calcium hydride, subsequently found at Mount Wilson by Olmsted, the great majority of the lines of spot spectra are now accounted for. Whether any of these magnesium hydride lines are present in the normal solar spectrum is still an open question. In any case, only a very small percentage of the faintest lines of the sun can be attributed to this origin.

Another element to which he has devoted much attention is scandium, already known to be present both in prominences and in spots. In this research he exhibited his usual skill in experiment, and was able greatly to extend our knowledge of the spectrum. He showed that it consisted of two distinct classes of lines, one occurring as high-level lines in the chromosphere, strong in the sun and weak in spots, and the other, not recorded in the chromosphere, very feeble in the sun and strong in spots.

The first class corresponded to the enhanced lines, those stronger in the spark than in the flame or arc, and the second comprised the relatively strong arc lines. No evidence of a combination of scandium and hydrogen could be obtained, though an oxide was probably the origin of certain flutings. Barium and strontium hydrides were also studied, but are apparently not present in spots.

This short outline of our Medallist's work on spot spectra will, I trust, be a sufficient indication of the value and range of his researches, and will illustrate the point mentioned in my preliminary remarks, the close union he has kept between experiment and observation. I feel confident that as regards the latter he would, if asked, like to express his indebtedness to other observers, especially to those favoured with clearer skies and more powerful instruments than he has had at his disposal.

I now pass to another, but closely allied subject, the spectra of third-type stars.

The origin of the characteristic bands in the spectra of stars of Secchi's type III. or Vogel's class III.*a*, sometimes called the Antarian stars, had remained a mystery from their first observation in 1864 until they were identified by Professor Fowler with bands of titanium oxide in 1904. These bands had previously escaped notice in the laboratory, and very considerable experimental work was necessary to produce them satisfactorily and for definite conclusion as to their origin to be inferred. In the earlier experiments ample evidence was obtained that they were due to titanium; it was only as the result of a somewhat prolonged and difficult quest that their true source was found to be the oxide of that element.

From an astrophysical point of view this was significant as showing conclusively not only that these stars were at a sufficiently low temperature for this compound to be formed, but also as demonstrating the presence of oxygen, of which there was otherwise no direct evidence. The subsequent discovery of the less refrangible titanium oxide bands in sunspots has already been mentioned. The search for them in sunspots was a natural outcome of their previous recognition in type III. stars.

A notable instance of the predominance of titanium oxide in stellar spectra is found in α Ceti. Using for purposes of comparison the beautiful photographs obtained by Mr. Slipher at the Lowell Observatory, and placing these in juxtaposition with spectra obtained in his own laboratory, Professor Fowler was able to demonstrate a complete identity, extending through the whole range of the photographs up to the extreme red at $\lambda 7054$, thus including a group of three bands previously recorded by Newall and Cookson in α Orionis.

With the addition of some bright hydrogen lines and some metallic lines, principally those of vanadium, iron, and titanium, and also, but somewhat feeble, those of sodium, the whole of the α Ceti spectrum is thus accounted for, with the possible exception of two bands which are not yet fully elucidated but are

quite probably also titanium oxide bands with a relative intensity slightly different from that hitherto obtained under artificial conditions. Whether this variation in relative intensity is due to the addition of some unidentified metallic lines or to some physical condition not yet reproduced in the laboratory remains uncertain.

Having thus asked you to follow me in this very hasty glance at our Medallist's work upon the stars, I now invite you to return to the solar system and to follow me for a few minutes in an attempt to summarise his discoveries on the spectra of comets. I should rather say the spectra of comets' tails. The spectrum of the head had been long since observed, first by Donati in 1864, by Sir William Huggins on many occasions, visually in 1866, 1867, and 1868, and photographically in 1881, and by numerous other observers. The head spectrum was established to be a twofold one, consisting firstly of bands due to carbon compounds, and secondly, of bright metallic lines, due to sodium, magnesium, and iron, appearing only when the comet was near perihelion and sometimes, as in the great comet of 1882, becoming very strong upon close approach to the sun. While thus the main features of the head spectrum are satisfactorily explained, there remain some minor details, notably a group in the violet in the neighbourhood of $\lambda 4050$, still unidentified.

Up to 1907 all attempts to obtain trustworthy records of the spectrum of the tail had proved abortive, the luminosity was too feeble for any of the instruments available. About then it occurred to several astronomers that by the use of the prismatic camera with the dispersion arranged at right angles to the general line of the tail it might be possible to get a record of the spectrum in spite of the extreme faintness of the light. This supposition proved correct, and successful photographs were obtained first of Daniel's comet in 1907, and again, with particularly good results, of comet Morehouse in 1908.

The tracing of these spectra to their source and their reproduction in the laboratory, under experimental conditions, was a problem to which our Medallist set himself with his accustomed skill and energy. It proved no easy task. In view of the low density of the gases concerned, the most promising field of investigation seemed to be that of the kathode spectra of carbon compounds and other gases at very low pressures. He had by him a series of plates, taken some years before, of the kathode discharge of tubes initially filled with hydrogen, and on re-examining these and comparing them with the comet spectra obtained by the prismatic camera he found one of them, differing greatly from the others, which showed an almost complete identity; not only did the various bands agree in position with those of the comet, but the relative intensities were similar throughout. This was a hopeful beginning, but it remained now, firstly, to reproduce the spectrum under conditions of rigorous control and, secondly, to determine the chemical origin of the bands. The first portion of this task proved comparatively easy. On again pre-

paring a tube in the same manner as before and gradually reducing the pressure the bands came into view when the pressure sank to 0.01 mm. The second part was by no means so simple. Experience had shown that at very low pressures the final spectrum obtained depended not so much upon the original gas introduced as upon minute quantities of impurities, particularly nitrogen and carbon compounds. It was noticed in the experiments that while the gas pressure was being reduced there was always a stage when certain bands, commonly designated the "carbonic oxide" bands, appeared; and it was found that the comet bands could be obtained as easily when the tube was originally filled with carbon monoxide as after filling with hydrogen.

This led to the inference that the source of the bands was a carbon compound, though it was not yet clear what precise compound it was. The difficulties of determining this were very great. The same difficulty had always been found with the banded spectra of carbon and its compounds. Thus the ordinary "Swan" or candle-flame spectrum had been variously attributed to carbon itself, hydrocarbons, and carbon monoxide, while it is still doubtful what is the real source of the hydrocarbon spectrum, probably, but not certainly, acetylene.

However, in short I may say that as the result of a most searching series of experiments Professor Fowler was able to show conclusively that these bands were due to carbon monoxide of very low density, a conclusion in complete harmony with previous knowledge of the spectra of the heads of comets.

This discovery threw light on an old observation of Sir William Huggins of the spectrum of Brorsen's comet in 1868. As observed by him it consisted of three bands differing considerably in position from those of the "Swan" spectrum of carbon usually observed. An attempt was made later to explain these differences by assuming that some systematic error had arisen in fixing their position. This supposition, always, it may be noted, an extremely rash one in the case of this observer, proved to be quite beside the mark, and a comparison of the wave-lengths of the Brorsen comet bands with those of comet Morehouse and the low-pressure carbon monoxide showed there was a great similarity between the spectra of the two comets, and that the difference lay in the fact that the earlier comet showed the low-pressure "tail" spectrum in the close vicinity of its nucleus. Sir W. Huggins had, in fact, observed, and recorded with an accuracy quite as high as could be expected with such a faint object, the low-pressure spectrum of carbon monoxide.

An interesting by-product of this investigation was the discovery of a new band spectrum of this same compound occurring at comparatively high gas pressures, *i.e.* about 100 mm. The possible presence of these bands in some comet spectra is indicated, and a not unlikely source of error, arising from the fact that the brightest part of the yellow band is almost coincident with the sodium line, is pointed out. Thus Sir David Gill, viewing the

great comet of 1882 through a direct vision spectroscope, saw a yellow monochromatic image extending to 3 or 4 degrees from the nucleus. This distance would correspond to many millions of miles, to which it is almost impossible to conceive that sodium vapour could extend, and a possible alternative is that the yellow image was due, at all events in part, to the conspicuous presence of this high-pressure carbon monoxide band. This does not imply the casting of any doubt upon the presence of sodium in the head, which seems fully established.

I have now almost completed my cursory survey of that portion of our Medallist's work which has a direct astrophysical bearing, but I cannot leave it without mention of a subject well known to most of you, his observations of solar eclipses.

He was associated with Sir N. Lockyer on many of these occasions, and did much to advance knowledge of the solar chromosphere. Thus in 1893 he obtained the first really successful photographs with the prismatic camera, and was able to differentiate clearly, for the first time, between the chromosphere and corona spectrum. In 1898 the true wave-length of the green corona line was determined, and beautiful records obtained of the distribution of coronium in the corona. Quite recently he has, at the same time as Professor Newall, shown how it was possible to record the flash spectrum during the partial phases of an eclipse, a very promising method of observation which ill fortune prevented him testing effectively in August last.

The remainder of Professor Fowler's work would, I feel, necessitate another address to do any real justice to it. I must perforce pass it over now with slight notice, firstly, because time does not permit me to treat of it at all fully and, secondly, because, while most of it has a distinct astrophysical bearing, the work itself is physics rather than astronomy, and therefore not suitably dealt with from this chair.

I shall therefore merely allude to his extraordinarily important investigations on series lines in spectra; of hydrogen and helium, where he reproduced in the laboratory the Pickering series, until then only observed in a few stars, and the well-known line "4686," so important in the spectra of some nebulae and stars of the earliest types; of magnesium, where he obtained new series of spark lines additional to the two series of triplets which were known before, but to which he has added several members; of strontium, where he has added new members to the series of triplets, and of his general discussion of the whole question in the Bakerian lecture of last year. I also only mention his investigation of the spectrum of the active modification of nitrogen, discovered by Professor Strutt, and his laborious research on the carbon arc spectrum, wherein he traced the source of a multitude of lines in the yellow and red to cyanogen, a research which has possible important application to the spectra of comets and of type IV. stars.

We may note that the experimental reproduction of the

"Pickering" and "4686" series of lines, now assigned by him to "protohelium," has strengthened his conviction that there are no special kinds of matter in any of the celestial bodies, and that the resources of our laboratories are already adequate for the reproduction of most, if not all, celestial spectra. Physical questions of the greatest interest are aroused by these inquiries, and, when the mode of excitation of the atoms which generate these lines is better understood, a flood of light will doubtless be thrown on the constitution both of nebulae and of other bodies in which they are observed.

In bringing my short review of our Medallist's work to a conclusion, I must not forget a point upon which the gratitude of all astronomers is due to him—his skill as an organiser and a teacher. With no excessive amount of funds at his disposal, he has succeeded in bringing the spectroscopic laboratory of the Imperial College of Science up to a high standard of efficiency, and, as is evidenced by the number of papers published by his assistants and pupils, the standard of work set in this laboratory is no less high. Spectroscopy with an astrophysical bias might be the motto written up over the entrance, and all pupils who will follow this track are welcomed and encouraged.

Professor Fowler is a comparatively young man, and I am confident that every Fellow of the Society will join me in wishing him long life and strength, and will look to his skill and perseverance to throw further light on many obscure points in the chemical constitution and physical condition of celestial bodies.

The President, then handing the Medal to Professor Fowler, addressed him in the following terms:—

Professor Fowler: I deem myself fortunate that among the duties of this chair it has fallen to my lot to hand you this Medal and to express, however inadequately, my appreciation of your past achievements and my hopes for your future successes. I ask you to accept it as a token of our regard and esteem, and as a witness of our high estimation of your devoted and patient labours.

The Meeting then proceeded to the election of the Officers and Council for the ensuing year, when the following Fellows were elected:—

President.

R. A. SAMPSON, Esq., M.A., D.Sc., F.R.S., Astronomer Royal for Scotland.

Vice-Presidents.

J. W. L. GLAISHER, Esq., M.A., Sc.D., F.R.S.

Col. E. H. HILLS, C.M.G., D.Sc., F.R.S.

W. H. MAW, Esq., LL.D.

H. H. TURNER, Esq., D.Sc., D.C.L., F.R.S., Savilian Professor of Astronomy, Oxford.

Treasurer.

E. B. KNOBEL, Esq.

Secretaries.

A. S. EDDINGTON, Esq., M.A., M.Sc., F.R.S., Plumian Professor of Astronomy, Cambridge.

ALFRED FOWLER, Esq., F.R.S.

Foreign Secretary.

ARTHUR SCHUSTER, Esq., Sc.D., Ph.D., Sec. R.S.

Council.

SYDNEY CHAPMAN, Esq., B.A., D.Sc.

Rev. A. L. CORTIE, S.J.

A. C. D. CROMMELIN, Esq., B.A., D.Sc.

Sir F. W. DYSON, M.A., LL.D., F.R.S., Astronomer Royal.

C. R. D'ESTERRE, Esq.

WALTER HEATH, Esq., M.A.

J. H. JEANS, Esq., M.A., F.R.S.

H. F. NEWALL, Esq., M.A., D.Sc., F.R.S., Professor of Astrophysics, Cambridge.

J. W. NICHOLSON, Esq., M.A., D.Sc., Professor of Mathematics, King's College.

Rev. T. E. R. PHILLIPS, M.A.

H. C. PLUMMER, Esq., M.A., Royal Astronomer of Ireland.

A. A. RAMBAUT, Esq., M.A., D.Sc., F.R.S., Radcliffe Observer.

